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CANADIAN AIR CUSHION TECHNOLOGY SOCIETY

SOCIÉTÉ CANADIENNE POUR LA TECHNOLOGIE DU COUSSIN D'AIR

PAPERS ON AIR CUSHION TECHNOLOGY

ICEBREAKING, COLD WEATHER OPERATIONS, VEHICLES

COMMUNICATIONS SUR LA TECHNOLOGIE DU COUSSIN D'AIR

DÉGLAÇAGE, EXPLOITATION PAR TEMPS FROID, VÉHICULES

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DÉGLAÇAGE, EXPLOITATION PAR TEMPS FROID, VÉHICULES

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The papers are published in the language in which they were submitted. An abstract in both official languages is included for each paper.

Les opinions et les vues exprimées dans ces documents sont celles des auteurs et ne reflètent pas nécessairement celles du Centre de développement des transports de Transports Canada, de la Société pour la technologie du coussin d'air et de l'Institut aéronautique et spatial du Canada.

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16. Abstract

The Canadian Air Cushion Technology Society (CACTS) has collected for publication a number of papers that were to be presented at its annual conference in September 1989. Due to special circumstances, this conference was cancelled.

The papers discuss a number of aspects of air cushion technology including: icebreaking with air cushion vehicles, numerical simulation of over water heave motion, exploratory tests on air cushion icebreaking concepts, hovercraft operations in Antarctica and China, and a technical evaluation of the MARIC 65-tonne amphibious hovercraft.

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16. Résumé

La Société canadienne pour la technologie du coussin d'air (CACTS) a réuni, pour publication, les communications reçues pour la conférence qui était prévue en septembre 1989 et qui a été annulée.

Ces documents traitent du déglaçage par véhicules à coussin d'air, de la simulation numérique d'un aéroglisseur à deux dimensions, d'essais sur maquettes de deux brise-glace à coussin d'air, de l'exploitation d'aéroglisseurs dans l'Antarctique, de l'essai d'un aéroglisseur sur la rivière Song-Hua et de l'évaluation technique du MARIC 722.

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INTRODUCTION

The Canadian Air Cushion Technology Society (CACTS) was active in its field in 1989. A number of papers on air cushion technology were presented to the American Institute of Aeronautics and Astronautics' Conference on Intersociety Advanced Marine Vehicles in June 1989. Unfortunately, this left few resources for the annual CACTS conference – the small number of registrations led to the cancellation of the 1989 conference.

The conference was to have featured a number of papers on icebreaking with air cushion vehicles, and on cold weather operations of hovercraft, in addition to a design workshop. This publication groups those papers received at the date of cancellation.

Three papers are presented on icebreaking: Dr. Carter discusses a method whereby one can calculate the performance of an icebreaking hovercraft at low speed, with the speed effect accounted for by means of an amplification factor. Dr. Hinchey looks at numerical simulation of the behaviour of an air cushion vehicle over water in order to determine stability limits of oscillations in the air cavity. The third paper, by B. Colbourne et al., looks at non-dimensional parameters for icebreaking with air cushion vehicles and uses them to evaluate test results with two models of air cushion icebreakers.

Two papers are presented on cold weather operations: J.S. Dibbern reviews recent hovercraft operations in Antarctica and indicates advantages and limitations of such operations. Zhao Jian et al. report on the trials of the MARIC Model 7210 hovercraft at the beginning of the icing season in northern China.

INTRODUCTION

En juin 1989 a eu lieu la conférence de l'American Institute of Aeronautics and Astronautics sur les véhicules marins. Cette conférence a réuni un grand nombre de communications sur la technologie du coussin d'air ce qui a limité les ressources pour la conférence de la Société canadienne pour la technologie du coussin d'air (CACTS), qui était prévue en septembre 1989. Le très petit nombre de participants enregistrés à la veille de la conférence a entraîné son annulation.

Cette conférence devait traiter de l'utilisation des véhicules à coussin d'air comme brise-glace, ainsi que de leur exploitation par temps froid; il était également prévu un atelier sur la conception d'aéroglisseurs spécialisés. Ce recueil présente les communications reçues à la date de l'annulation de la conférence 1989.

Trois documents concernent le déglaçage : le premier, par le Dr Carter, décrit une méthode de calcul de la rupture de la glace par aéroglisseur à basse vitesse; il tient compte de l'effet de la vitesse à l'aide d'un facteur d'amplification lié à l'apparition de vagues. Le second, par le Dr Hinchey, présente une simulation numérique du comportement d'un véhicule à coussin d'air au-dessus de l'eau afin de déterminer la stabilité des oscillations de la pression du coussin d'air. Le troisième, par B. Colbourne et al., élabore des paramètres non dimensionnels pour la rupture de la glace à l'aide d'un coussin d'air et les utilise pour l'évaluation des résultats d'essai de deux maquettes de brise-glace à coussin d'air.

Deux documents concernent l'exploitation par temps froid : le premier, par J.S. Dibbern, parle de l'utilisation des aéroglisseurs dans l'Antarctique et en indique les avantages et les limites d'utilisation. Le second, par Zhao Jian et al., rapporte l'essai de l'aéroglisseur MARIC 7210 au début de la saison froide dans le nord de la Chine.

The final paper describes the history of a 65-tonne development hovercraft, designed by MARIC in 1974, and retired in 1987 after a long life of useful testing.

Le dernier document décrit l'aéroglisseur MARIC 722, d'une masse de 65 tonnes, conçu en 1974 comme véhicule expérimental et qui a été réformé en 1987 après une longue durée d'expérimentation.

The 1989 hiatus in CACTS conferences will be put to good use in revising the Society's approach. Annual conferences did strain resources; the organizing committee is considering variable periods for the holding of these events, i.e. from 24 to 30 months. The publication of collected papers, such as this, and holding specialized workshops could aid in maintaining liaison between conferences. CACTS welcomes comments from the membership on these alternatives.

La suspension en 1989 de la série de conférences de la CACTS, sera mise à profit pour réviser notre méthode de travail. La périodicité annuelle nous semble trop contraignante; un intervalle de 24 à 30 mois serait mieux approprié. La publication des recueils tels que celui-ci, la tenue d'ateliers spécialisés, permettrait de faire le lien entre les conférences. La CACTS aimerait recevoir les commentaires de ses membres à ce sujet.

ICEBREAKING

DÉGLAÇAGE

NOTES ON ICEBREAKING WITH AIR CUSHION VEHICLES
(NOTES SUR LE DÉGLAÇAGE PAR VÉHICULES À COUSSIN D'AIR)

Dr. D. Carter, Donald Carter & Associés, Consultants

ABSTRACT

This paper presents a theoretical approach to the icebreaking of floating ice plates using air cushion vehicles (ACVs). It consists of a brief survey of analytical equations to determine the response of floating ice sheets to moving ACVs. Deflection and strain under a load moving at constant speed are maximized when the speed is equal to a critical value (Vc) function of craft length and water depth. At low vehicle speeds (V < 0.5 Vc) the ice sheet behaviour is similar to that generated by a stationary load. Examples of the calculation procedures are given and the results compare favourably with published data.

RÉSUMÉ

Le présent article se veut une approche théorique à l'utilisation de véhicules à coussin d'air pour briser les glaces flottantes. Il consiste en une brève revue des équations analytiques pour déterminer la réaction de la couverture de glace flottante sous des charges mobiles. La déflexion et les déformations internes de la glace atteignent leur maximum à une certaine vitesse critique de la charge, Vc, fonction de la longueur du véhicule et de la profondeur d'eau. À de faibles vitesses (V < 0,5 Vc), le comportement du champ de glace est similaire à celui observé sous une charge stationnaire. Des exemples de calcul sont présentés et les résultats se comparent bien avec les mesures publiées.

NOTES ON ICEBREAKING WITH AIR CUSHION VEHICLES

BY

D. CARTER

INTRODUCTION

When an air cushion vehicle (ACV) is bouncing on its cushion in one spot or moving on a floating ice sheet, the loading "felt" by the ice corresponds to a uniform pressure over the projected craft area.

Observations from uniform loading tests show that ice cover failures occur in two stages: first the ice cracks radially as soon as the stress under the load reaches the allowable stress. As the load increases, additional crack tries to divide the remaining section of plate in half creating ultimately eight 45 sections or wedges. This cracking pattern is often observed, but frequently only six wedges are formed, probably due to non-uniform ice properties.

These radial cracks emanating from the loaded area alter the stress distribution and the plate theory can no longer be applied to predict the formation of circumferential tip-breaking cracks. Final failure is rather associated with breaking off tips of uniformly loaded wedges floating on water (Figure 1).

1. BASIC ASSUMPTIONS

The analyses of floating ice plates subjected to vertical loads are generally based on the linear bending theory of elastic and homogeneous plates.

Recent observations, as well as laboratory measurements, indicates that ice can be assumed to respond elastically to stress if loaded to failure within about 100 s. (Traetteberg and others, 1975). Most bearing-capacity problems for moving loads, even for speed of travel as slow as 1 km/h , satisfy this condition and ice is essentially elastic (Gold, 1977).

However, one must question the degree of realism in assuming that ice is homogeneous since, in actual ice plates, the temperatures varies throughout the thickness. Namely, it is at about the freezing temperature at bottom surface, which rests on the water, and usually lower at the upper surface, which is in contact with the outside air. Because of this temperature gradient and the sensitivity of ice properties near freezing temperature, the elastic modulus, E, varies substantially throughout the plate thickness.

Keer and Palmer (1972) have proved that all solutions obtained for the homogeneous plate are applicable to floating ice plate problems only if the characteristic length, l, of the ice plates, is determined by the integration of the actual distribution of E across the plate thickness.

Carter (1986), assuming a linear temperature gradient, has obtained the following modified characteristic lengths for inhomogeneous ice plates:

a) freshwater columnar ice: $l = 14.3\ h^{4/4}$
b) freshwater granular ice: $l = 13.9\ h^{3/4}$
c) first-year sea ice: $l = 12.0\ h^{3/4}$
d) multi-year sea ice: $l = 12.2\ h^{3/4}$

Gold (1988) found experimentally that the characteristic length of freshwater ice covers grown in laboratory is in the range of 12.6 to 15.9 $h^{3/4}$ for extreme values of the elastic moduli.

The normal conditions of practice usually include an ice-water interface at the melting point, a gradient in temperature through the ice, imperfections such as cracks and air bubbles, variable thickness and ice type, and variable impurity content. An appropriate equation to be used for the calculation of the characteristic length is:

CHARACTERISTIC LENGTH: IS $l = 13\ h^{3/4}$ (1)

where l, the characteristic length, and h, the ice thickness, are expressed in metres.

2. AT LOW VEHICLE SPEEDS

The results of field tests obtained by Beltaos (1981) give support to Carter's (1977) theoretical deduction that, at vehicle speeds lower than half the critical speed which maximizes deflection and strain, the response of floating ice sheets is similar to that generated by a stationary load.

Nevel (1961) has solved the differential equation describing a wedge on an elastic foundation by means of a Frobenius power series. The wedge was considered a beam whose width, b, varied linearly with the distance, x, measured along the wedge bisector from the tip, i.e. $b = b_c x$ where b_c is a constant. The tip of the wedge was uniformly loaded for a distance x = R. (Figure 1)

The load factor required to break the uniformly loaded wedge was obtained by Nevel as:

LOAD FACTOR: $$\frac{6P}{b_c \sigma h^2} = F_{n_1} \qquad (2)$$

where: P : vertical load on the wedge;
b_c : width of the wedge at x = 1;
σ : bending tensile strength;
h : ice plate thickness

F_{n_1} is a function of the non-dimensional radius of load, r/l, and consists of a sum of four infinite series. Selected values of the load factor are given in the TABLE accompanying Figure 2.

Replacing the total vertical load by the product of the cushion pressure, p, by the loaded area:

$$P = \tfrac{1}{2} r \cdot b_c \cdot r \cdot p$$

and introducing that value in the above equation, we obtain the pressure factor required to break the uniformly loaded wedge as:

$$\frac{3 p r^2}{h^2 \sigma} = F_{n_1}$$

$$\frac{p}{\sigma} = F_{n_1} \cdot \frac{h^2}{r^2} \cdot \frac{1}{3}$$

From EQ. (1),

$$l^2 = 169\ h^{1.5}$$

which allows us to write:

$$\frac{p}{\sigma} = F_{n_1} \cdot \frac{h^2}{3r^2} \cdot \frac{l^2}{169\ h^{1.5}}$$

$$\frac{p}{\sigma} = F_{n_1} \cdot \frac{1}{(r/l)^2} \cdot \frac{h^{0.5}}{507}$$

PRESSURE FACTOR: $$\frac{507\ p}{\sigma h^{0.5}} = \frac{F_{n_1}}{(r/l)^2} = F_{n_2} \qquad (3)$$

Selected values of the pressure factor are given along with Figure 3. It can be seen that the minimum pressure required to break an ice plate corresponds to a non-dimensional radius of load equal to 2.

The above equation may be rewritten as:

$$h = \left(\frac{507}{F n_2} \cdot \frac{p}{\sigma}\right)^2$$

which gives the interrelation between the ice plate characteristics, the cushion pressure, and the radius of load.

Considering that:

a) the initial radial cracks emanate from the middle of the loaded area so that the radius of load corresponds to half the craft beam, B:

$$r = \frac{B}{2}$$

b) when the craft half-beam is larger than twice the ice plate characteristics length, the radius of load must pass through the critical condition, r/l = 2, as the vehicle progresses over the edge of the broken ice sheet.

The maximum ice thickness broken may them be obtained as a function of the ratio "cushion pressure/ice strength" and craft beam. The solution of the above equation is shown in Figure 4.

For those who are not familiar with such graphs, three examples have been worked out, in Figure 5, to illustrate the use of figure 4.

3. AT SPEEDS NEAR THE CRITICAL SPEED

Experience has shown that, under certain conditions of speed, ice thickness, and water depth, the ice breaking capability of an ACV may be increased considerably. The stress amplification in ice plates is caused by the combined effect of the cushion pressure plus the water wave set up by the motion of the load.

Assuming that the ice sheet is breaking under the ACV, so that the cushion pressure is directly interacting with the water surface, Carter (1977) integrated numerically the load distribution generated by the wave profile of uniform cushion pressures travelling at various speeds.

It is found that the stress amplification reaches its maximum value when the craft is travelling at the critical speed defined by:

CRITICAL SPEED: $V_c = 5 \sqrt{L \tanh \left(\frac{5H}{L}\right)}$ (km/h) (4)

in which L is ACV length (m); and H is water depth (m).

Figure 6 shows the critical speed, V_c, as a function of water depth and craft length.

At the critical speed, the maximum value of the amplified cushion pressure, p*, which corresponds to the cushion pressure plus the wave effect, is closely approximated by the following equation:

AMPLIFIED CUSHION PRESSURE: $p^* = 3.61\ p^{4/3}\ h^{1/3}$ (kPa) (5)

in which p is applied cushion pressure (kPa); and h is ice thickness (m). The above formula is a metric version of Carter's equation.

Figure 7 shows the amplified cushion pressure, p*, of ACV travelling at critical speed as a function of applied cushion pressure and ice thickness.

4. PRACTICAL APPLICATIONS

Figures 8 and 9 give examples of the calculation procedure as applied to VOYAGEUR and ACT-100. The given examples, more or less self-explanatory, proceed as follows:

AT LOW VEHICLE SPEEDS:

- STEP 1: Determination of the ratio "cushion pressure/ice strength".
- STEP 2: Determination, from Figure 4, of the maximum ice thickness broken corresponding to craft beam and ratio "cushion pressure/ice strength".

AT CRITICAL SPEEDS

- **STEP 3:** Determination of the critical speed by the use of Figure 6.

- **STEP 4:** Determination of the amplified cushion pressure from Figure 7.

- **STEP 5:** Determination of the ratio "amplified cushion pressure/ice strength".

- **STEP 6:** From Figure 4, determination of the maximum ice thickness broken corresponding to craft beam and ratio "amplified cushion pressure/ice strength".

As it can be seen, the calculation procedure is quite simple and straight forward and predictions are close to the published results of field tests of ice breaking with ACV travelling at various speeds.

5. CONCLUSIONS

Equations giving the response of floating ice sheets to ACV travelling at various speeds have been presented and evaluated for the normal conditions of practice. These equations have been demonstrated to give reasonable predictions for highly variable conditions of ice properties, water depths, and vehicle dimensions.

6. ACKNOWLEDGMENTS

The work presented herein is part of a continuing research program on ice breaking with Air Cushion Vehicle; this program is carried out by the Transportation Development Centre. Permission from Transport Canada to prepare this paper for publication is gratefully acknowledged.

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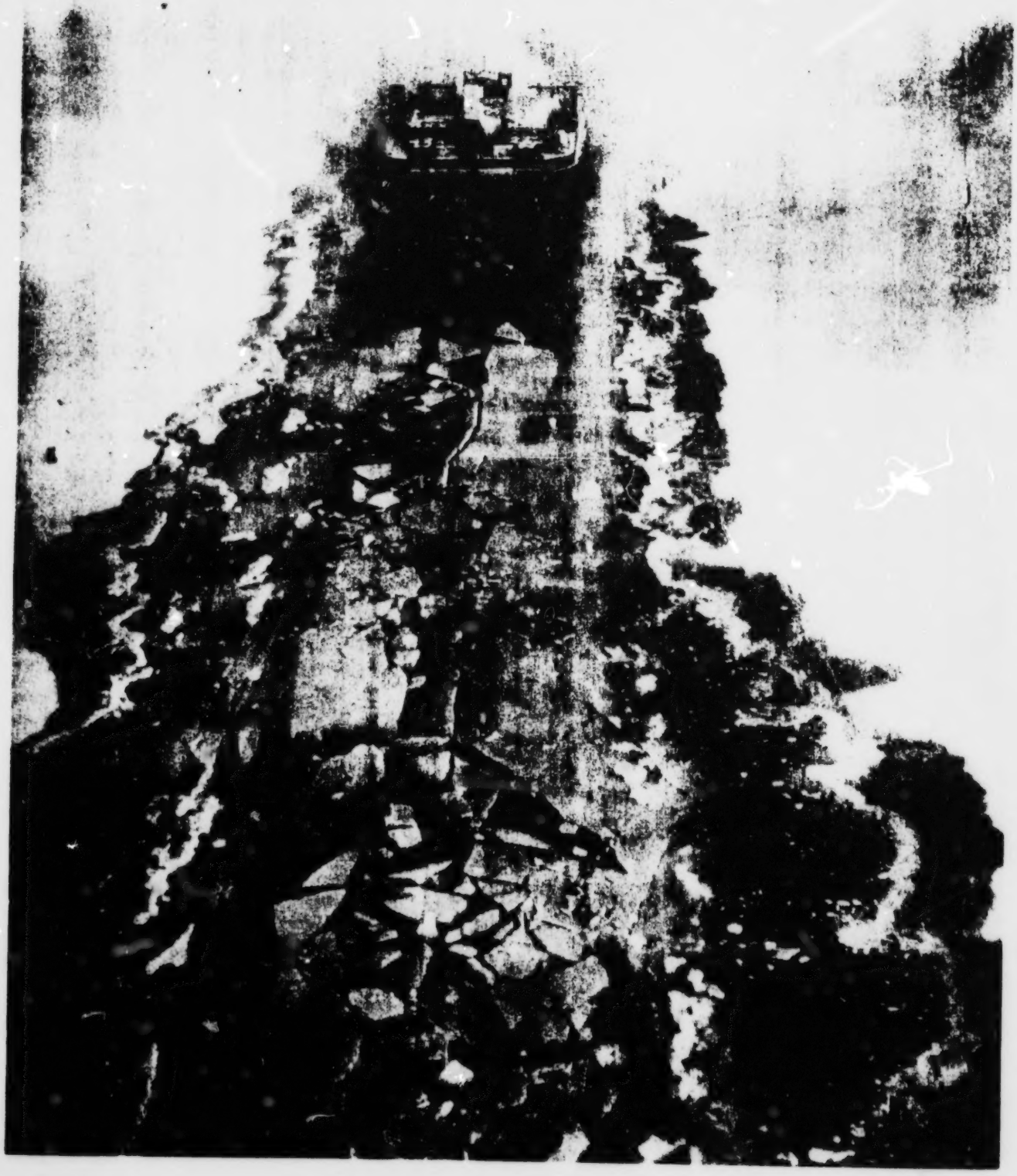
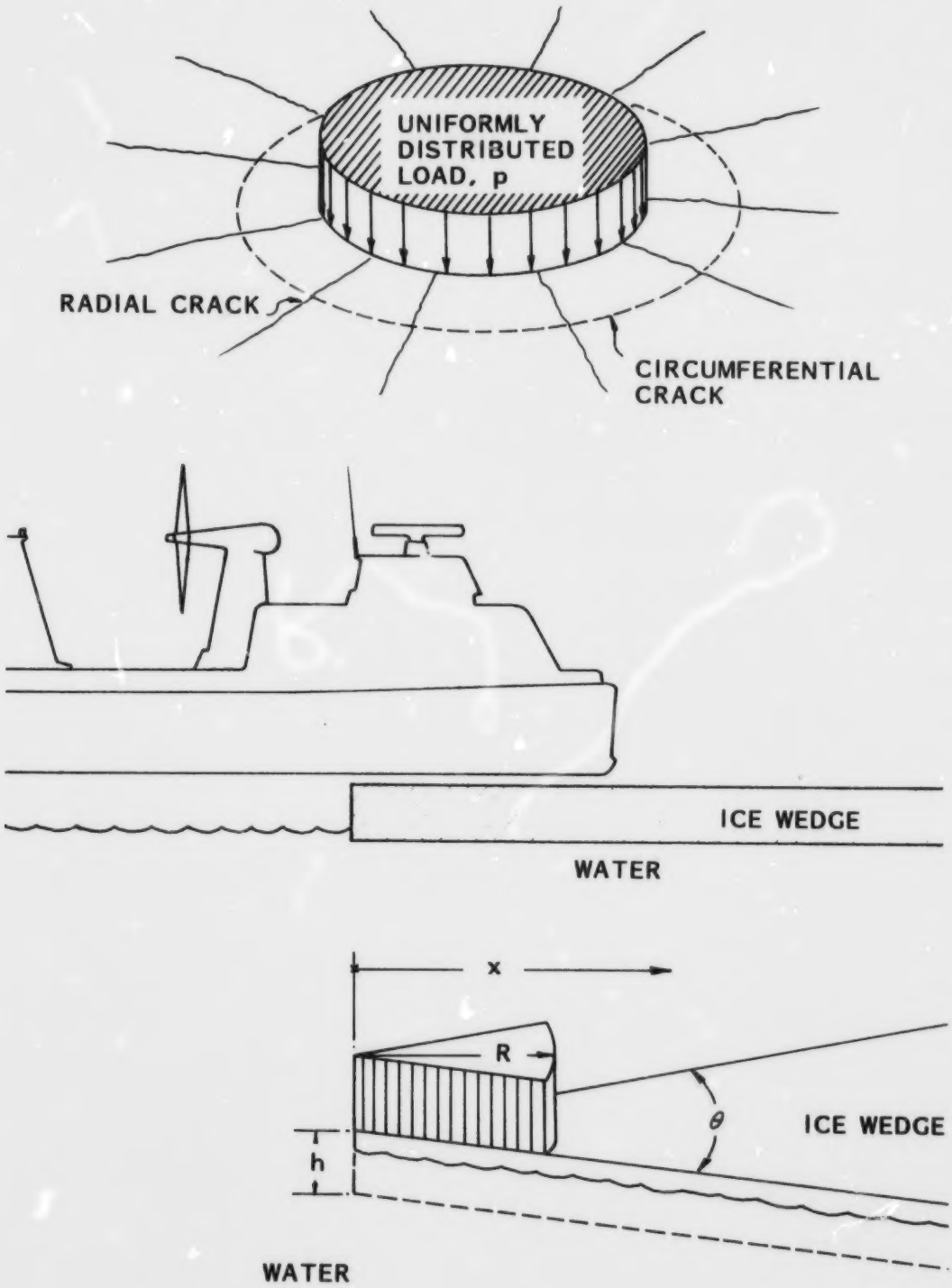


ACT-100 at a weight of 250 tons, breaking 22 inches of ice during MOT winching trials at Tuktoyaktuk, November 1972. *(Courtesy R.G. Wade, MOT.)*

PHOTO 1.

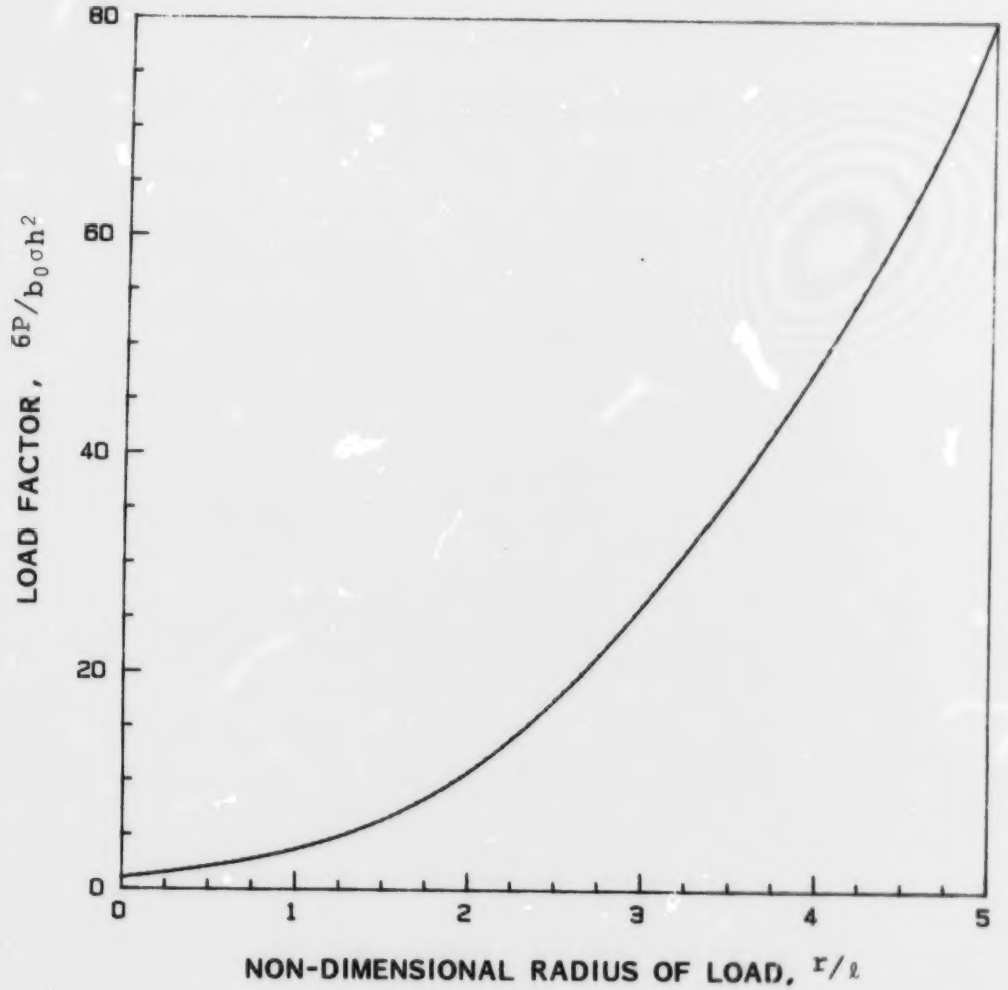


SCHEMATIC REPRESENTATION OF THE PROBLEM CONSIDERED.

FIGURE 1.

LOAD FACTOR

r/ℓ	LOAD FACT.	r/ℓ	LOAD FACT.	r/ℓ	LOAD FACT.	r/ℓ	LOAD FACT.
0.00	1.00	0.70	2.64	2.00	10.86	3.60	38.85
0.01	1.05	0.80	2.96	2.20	13.25	3.80	43.55
0.10	1.26	0.90	3.31	2.40	15.97	4.00	48.46
0.20	1.45	1.00	3.71	2.60	19.04	4.20	53.64
0.30	1.65	1.20	4.63	2.80	22.46	4.40	59.16
0.40	1.87	1.40	5.76	3.00	26.16	4.60	65.12
0.50	2.10	1.60	7.16	3.20	30.13	4.80	71.86
0.60	2.36	1.80	8.84	3.40	34.36	5.00	79.81

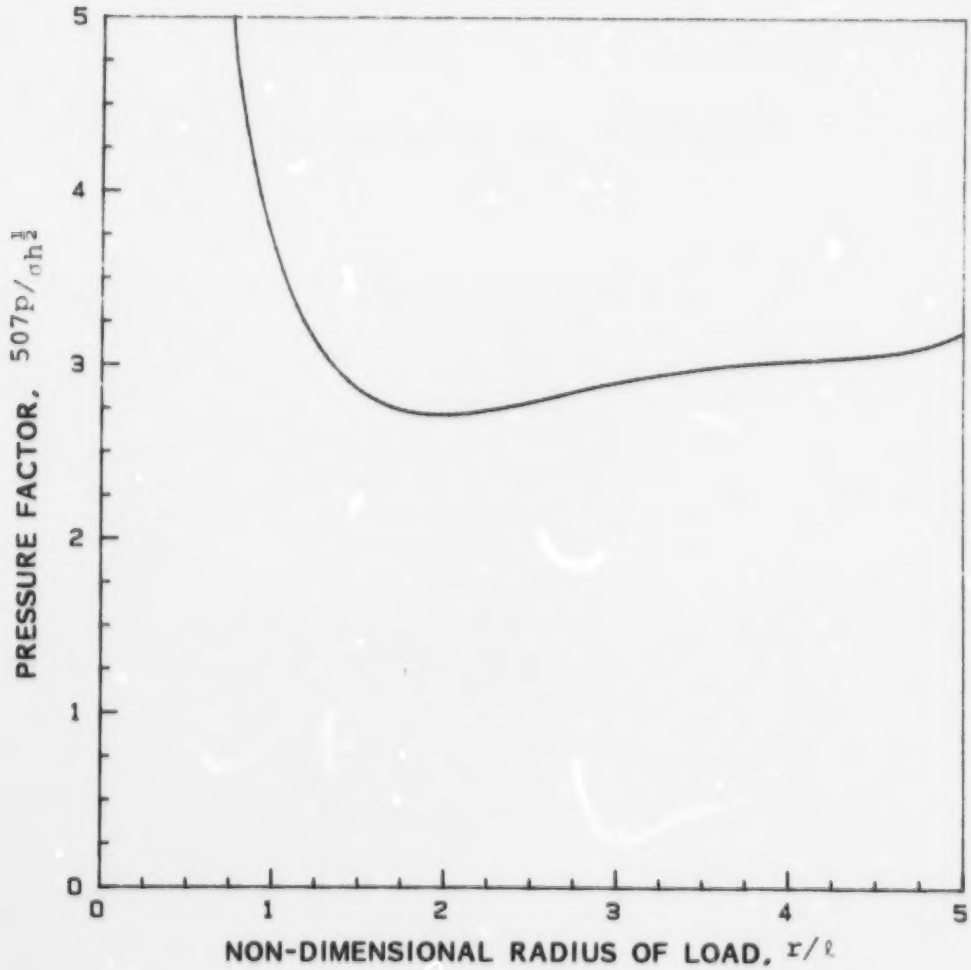


LOAD FACTOR REQUIRED TO BREAK A UNIFORMLY LOADED WEDGE ON AN ELASTIC FOUNDATION.

FIGURE 2.

PRESSURE FACTOR

r/ℓ	PRES. FACT.	r/ℓ	PRES. FACT.	r/ℓ	PRES. FACT.	r/ℓ	PRES. FACT.
0.00	****	0.70	5.39	2.00	2.72	3.60	3.00
0.01	****	0.80	4.62	2.20	2.74	3.80	3.02
0.10	****	0.90	4.09	2.40	2.77	4.00	3.03
0.20	36.30	1.00	3.71	2.60	2.82	4.20	3.04
0.30	18.37	1.20	3.21	2.80	2.87	4.40	3.06
0.40	11.67	1.40	2.94	3.00	2.91	4.60	3.08
0.50	8.41	1.60	2.79	3.20	2.94	4.80	3.12
0.60	6.55	1.80	2.73	3.40	2.97	5.00	3.19

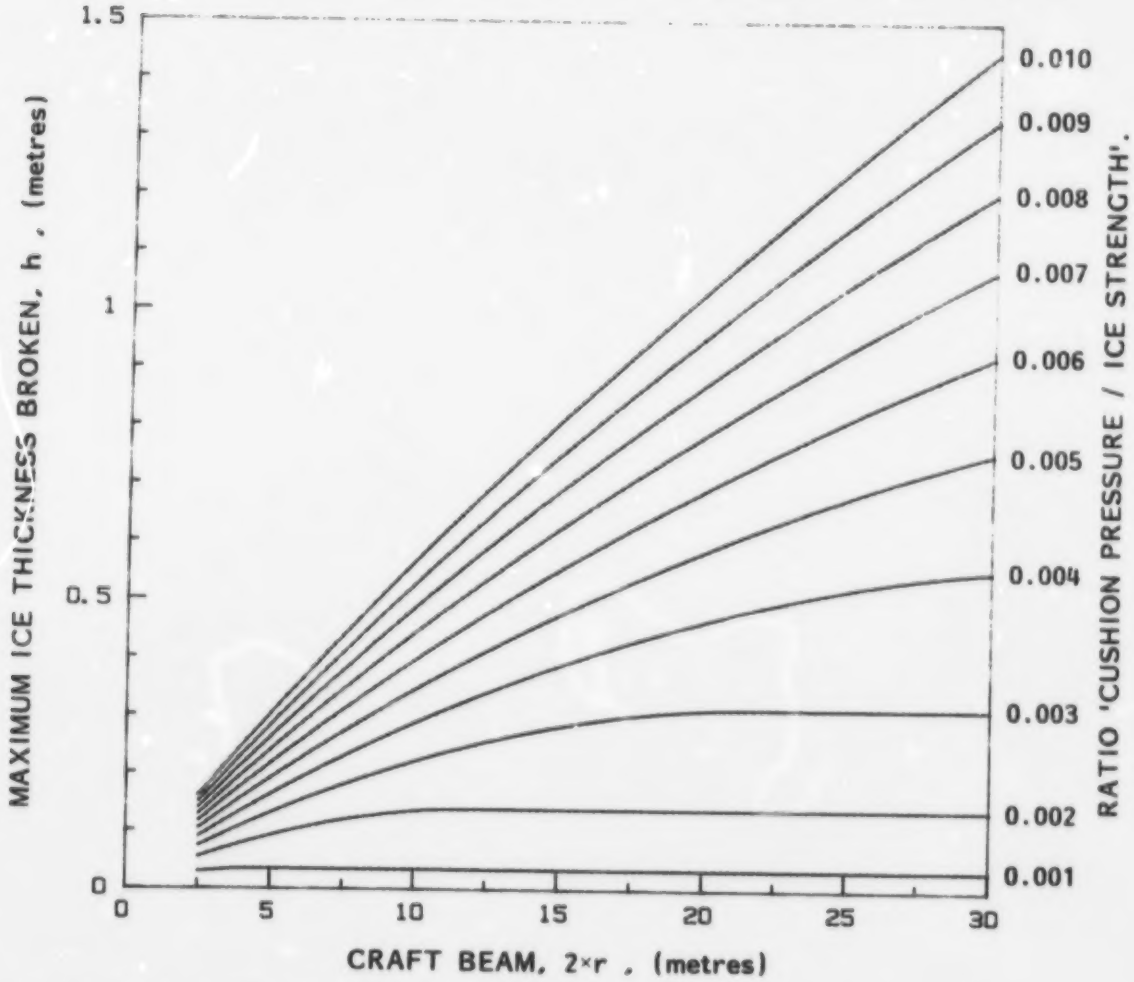


PRESSURE FACTOR REQUIRED TO BREAK A UNIFORMLY LOADED WEDGE ON AN ELASTIC FOUNDATION.

FIGURE 3.

MAXIMUM ICE THICKNESS BROKEN, h , (metres)

r/	RATIO "CUSHION PRESSURE / ICE STRENGTH"					
	0.001	0.002	0.004	0.006	0.008	0.01
0.2	0.000	0.001	0.003	0.007	0.012	0.020
0.4	0.002	0.008	0.030	0.068	0.121	0.189
0.6	0.006	0.024	0.096	0.215	0.383	0.599
0.8	0.012	0.048	0.192	0.433	0.770	1.202
1.0	0.019	0.075	0.300	0.674	1.198	1.872
1.2	0.025	0.100	0.399	0.897	1.594	2.491
1.4	0.030	0.119	0.476	1.070	1.902	2.972
1.6	0.033	0.132	0.526	1.185	2.106	3.291
1.8	0.035	0.138	0.552	1.242	2.209	3.451
2.0	0.035	0.139	0.558	1.255	2.230	3.485



MAXIMUM ICE THICKNESS BROKEN AS A FUNCTION OF CRAFT BEAM AND RATIO 'CUSHION PRESSURE / ICE STRENGTH'.

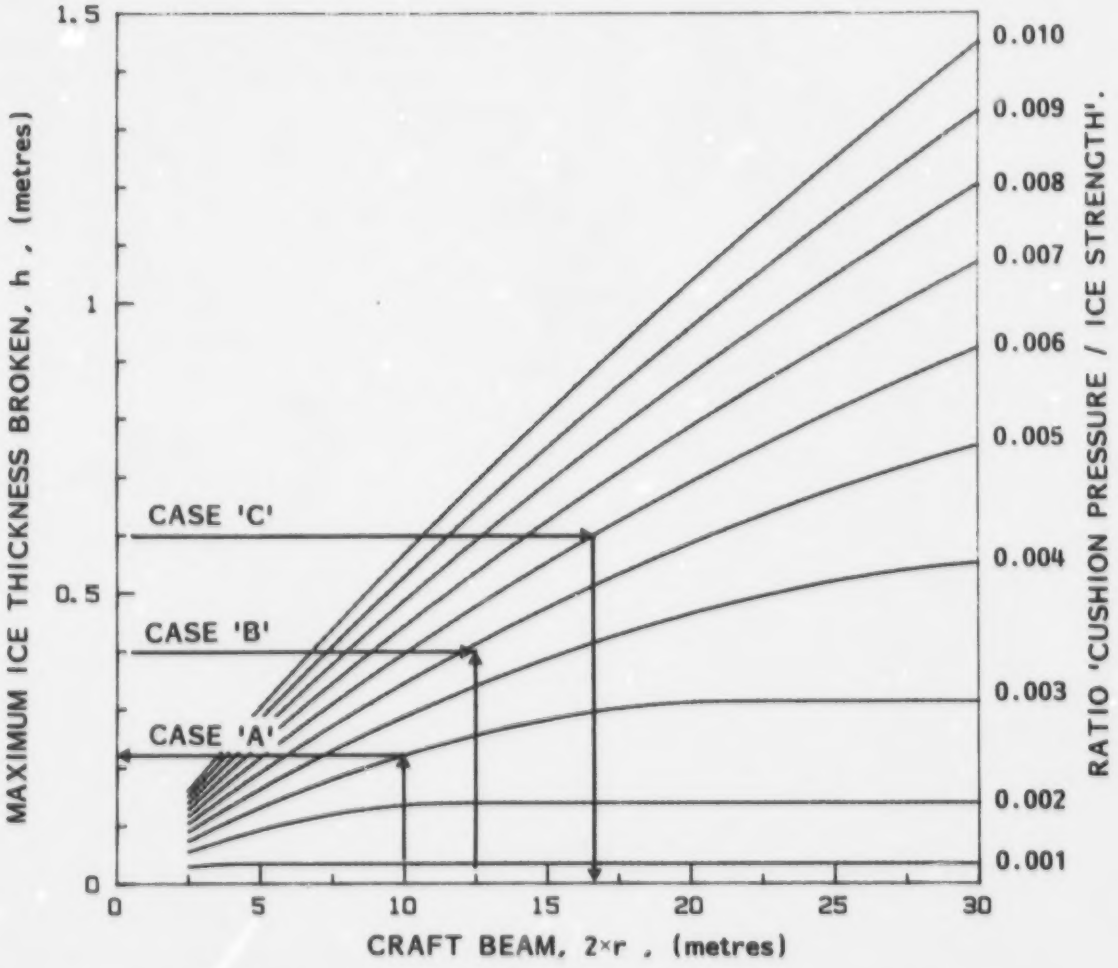
FIGURE 4.

EXAMPLES: ICE FLEXURAL STRENGTH : 500 kPa

CASE 'A': Being given : Cushion Pressure : 1.5 kPa.
and : Craft Beam : 10 m.
Find : Ice Thickness Broken (0.22 m)

CASE 'B': Being given : Ice Thickness : 0.4 m
and : Craft Beam : 12.5 m.
Find : Cushion Pressure (2.4 kPa)

CASE 'C': Being given : Ice Thickness : 0.6 m
and : Cushion Pressure : 3.0 kPa
Find : Craft Beam (16.5 m)

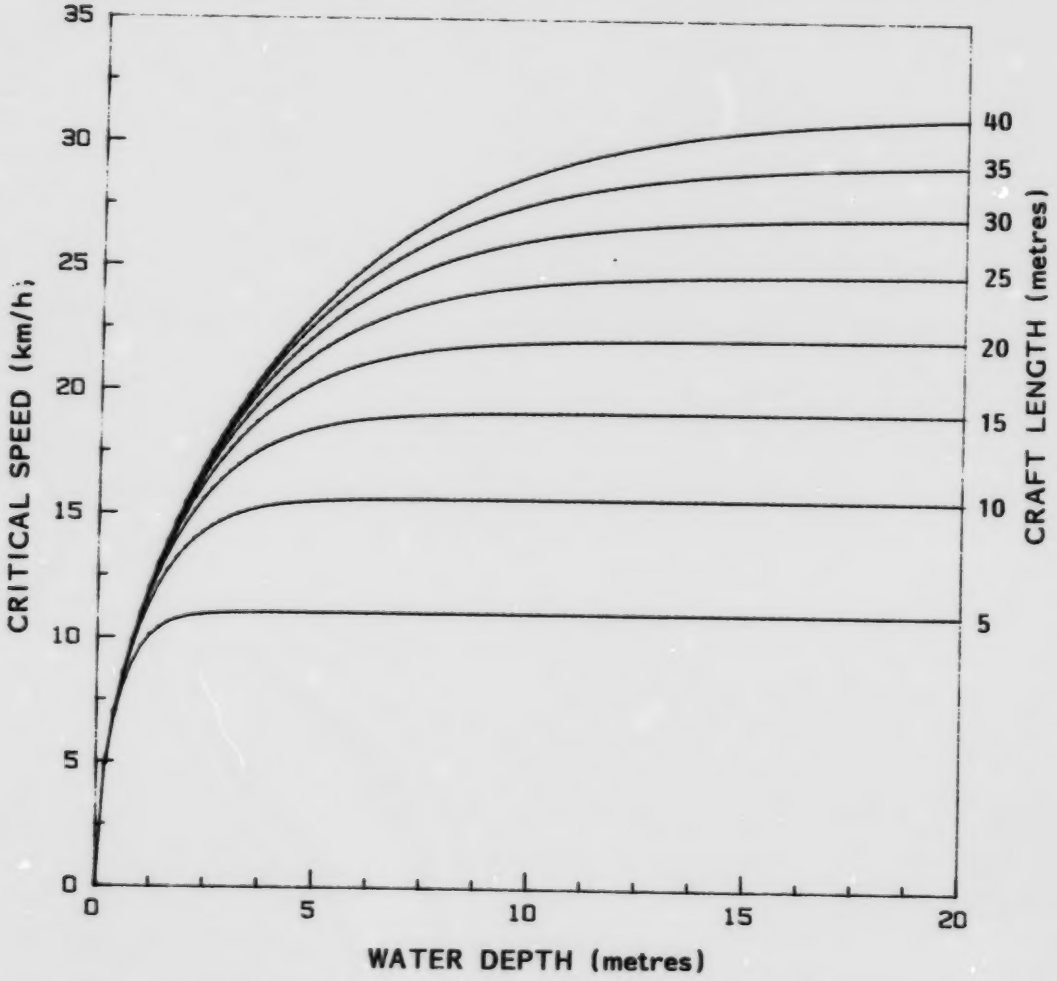


MAXIMUM ICE THICKNESS BROKEN AS A FUNCTION OF CRAFT BEAM AND RATIO 'CUSHION PRESSURE / ICE STRENGTH'.

FIGURE 5.

CRITICAL SPEED (km/h)

CRAFT LENGTH (m)	WATER DEPTH (metres)						
	5	10	15	20	25	30	35
5	11.07	11.07	11.07	11.07	11.07	11.07	11.07
10	15.54	15.65	15.65	15.65	15.65	15.65	15.65
15	18.48	19.15	19.17	19.17	19.17	19.17	19.17
20	20.35	21.98	22.12	22.14	22.14	22.14	22.14
25	21.54	24.28	24.68	24.74	24.75	24.75	24.75
30	22.32	26.13	26.92	27.08	27.11	27.11	27.11
35	22.85	27.60	28.87	29.18	29.26	29.28	29.28
40	23.22	28.77	30.55	31.09	31.24	31.29	31.30

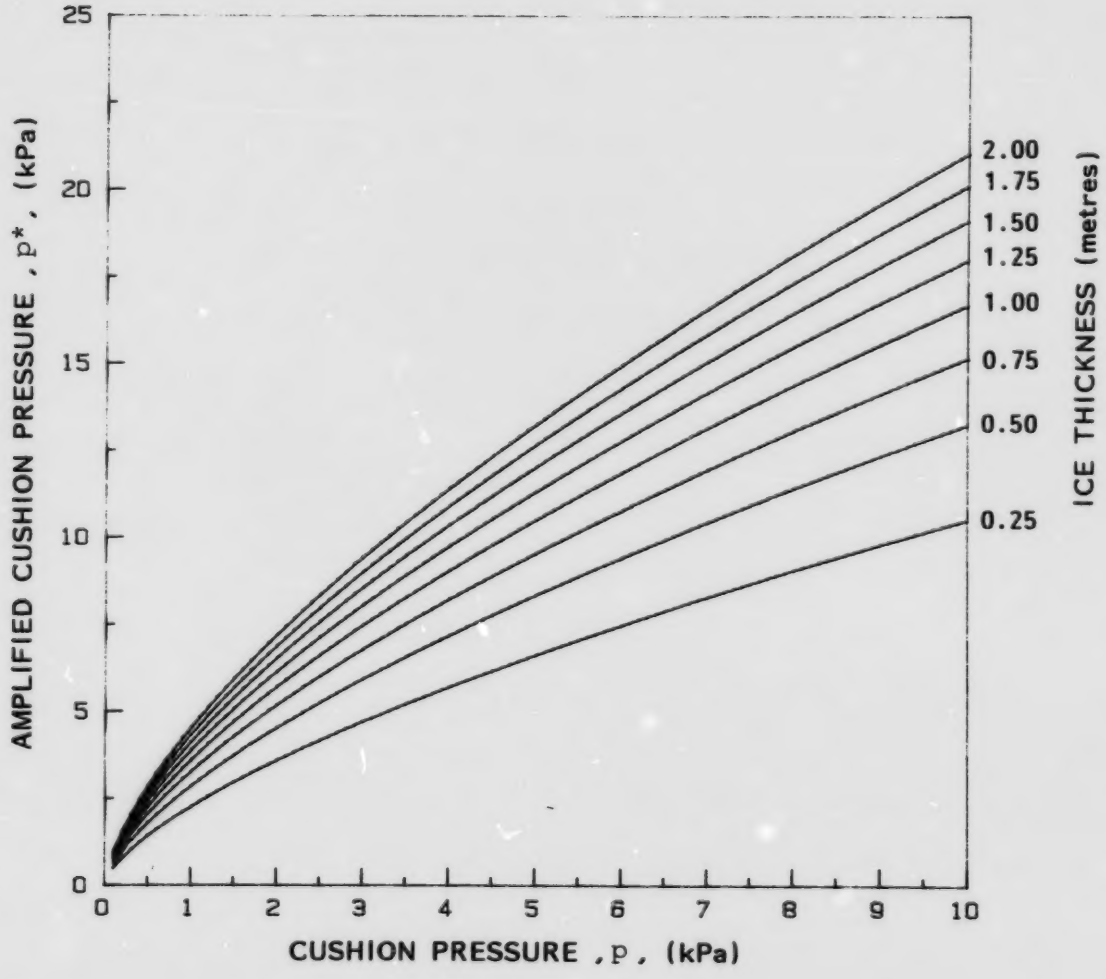


CRITICAL SPEED AS A FUNCTION OF WATER DEPTH AND CRAFT LENGTH.

FIGURE 6.

AMPLIFIED CUSHION PRESSURE , p*, (kPa)

p (kPa)	ICE THICKNESS (metres)						
	0,25	0,50	0,75	1,00	1,25	1,50	1,75
0.5	1.43	1.80	2.06	2.26	2.44	2.59	2.73
1.0	2.26	2.85	3.27	3.60	3.87	4.12	4.33
2.0	3.60	4.53	5.18	5.71	6.15	6.53	6.88
3.0	4.71	5.94	6.79	7.48	8.06	8.56	9.01
4.0	5.71	7.19	8.23	9.06	9.76	10.37	10.92
5.0	6.62	8.34	9.55	10.51	11.32	12.03	12.67
6.0	7.48	9.42	10.78	11.87	12.79	13.59	14.30
7.0	8.29	10.44	11.95	13.16	14.17	15.06	15.85



CUSHION PRESSURE AMPLIFICATION, AT CRITICAL SPEED, VERSUS APPLIED CUSHION PRESSURE AND ICE THICKNESS.

FIGURE 7.

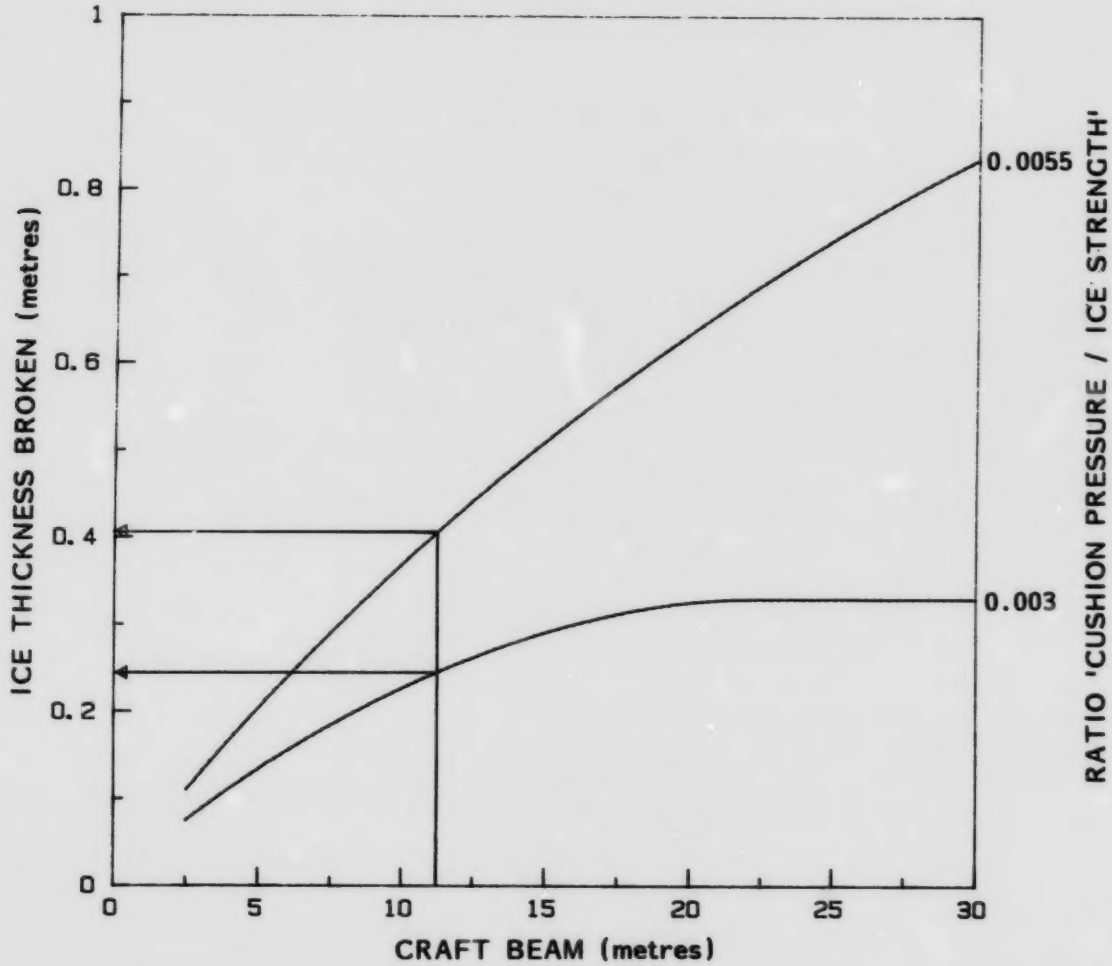
EXAMPLE 1.: VOYAGEUR Length:19.81m; Beam:11.27m; Pressure:2 kPa
Ice Flexural Strength : 650 kPa ($p/\sigma = 0.003$)

AS COMPUTED :
Static mode Ice Thickness = 0.24 m (9.5 inches)

Dynamic mode Critical Speed = 22 km/h (13.5 mph)
Amplified Cushion Pressure = 3.56 kPa ($p/\sigma = 0.0055$)
Maximum Ice Thickness = 0.40 m (16 inches)

AS OBSERVED* :
Critical Speed = 20 km/h (12.2 mph)
Ice Thickness = 0.23 to 0.38 m (9 to 15 inches)
depending on craft speed

*Wade,R.G.,Edwards,R.Y.,and Kim,J.K. (1975) - 'Improvements in Ice-Breaking by Use of Air-Cushion Technology', Paper presented at SNAME, ICE-TECH. 75.



VOYAGEUR : PREDICTION OF MAXIMUM ICE THICKNESSES BROKEN IN STATIC MODE AND DYNAMIC MODE, AT CRITICAL SPEED.

FIGURE 8.

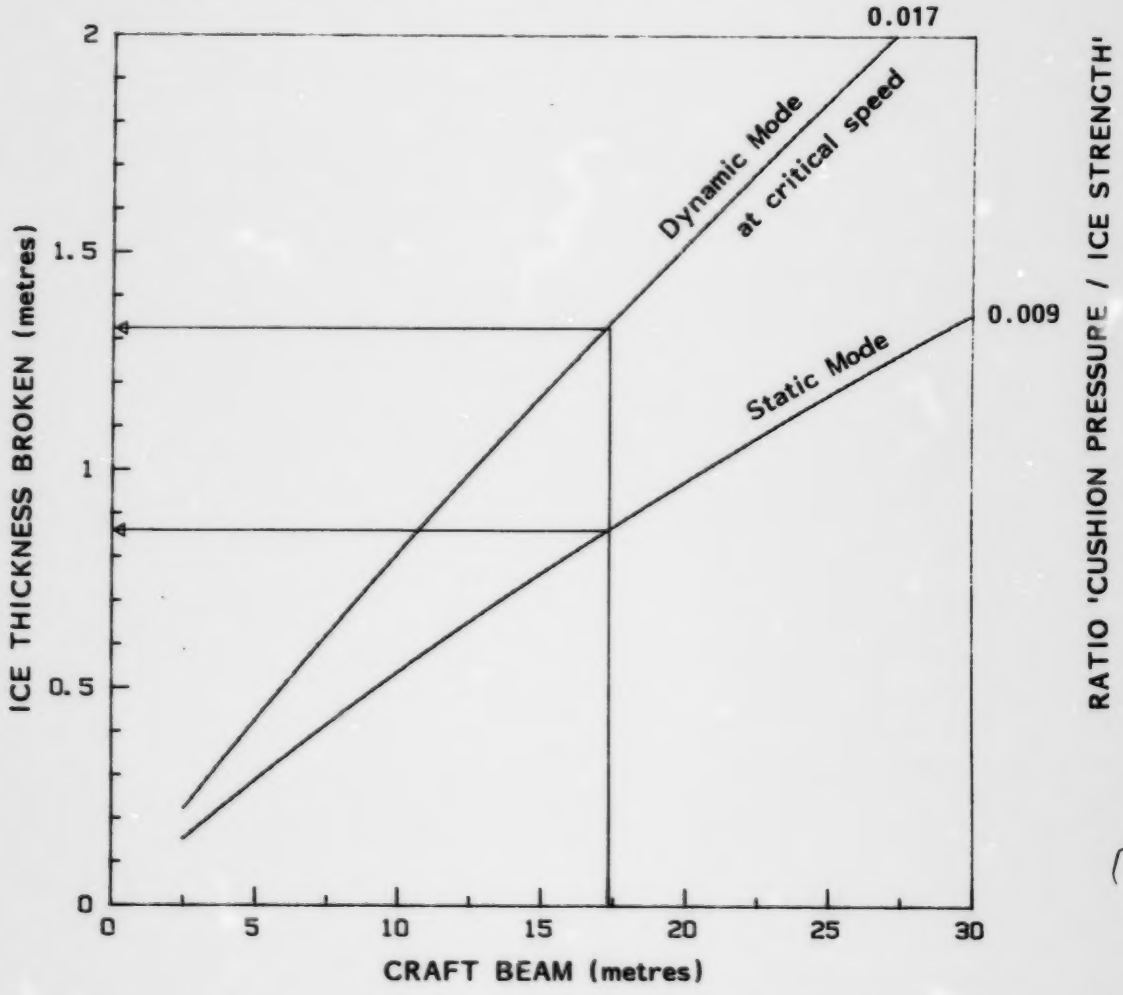
EXAMPLE 2.: ACT-100 Length:22.86m; Beam:17.37m; Pressure:6 kPa
Ice Flexural Strength : 650 kPa (p/ = 0.009)

AS COMPUTED :
Static mode Ice Thickness = 0.86 m (33 inches)

Dynamic mode Critical Speed = 23.7 km/h (14.7 mph)
Amplified Cushion Pressure = 11.3 kPa (p/ = 0.017)
Maximum Ice Thickness = 1.32 m (50 inches)

AS OBSERVED* :
Ice Thickness = 0.76 m at very low speed.

*Wade,R.G.,Edwards,R.Y.,and Kim,J.K. (1975) - 'Improvements in Ice-Breaking by Use of Air-Cushion Technology', Paper presented at SNAME, ICE-TECH. 75.



ACT-100 : PREDICTION OF MAXIMUM ICE THICKNESSES BROKEN IN STATIC MODE AND DYNAMIC MODE, AT CRITICAL SPEED.

FIGURE 9.

NUMERICAL SIMULATION OF OVER WATER HEAVE MOTION OF A TWO-DIMENSIONAL HOVERCRAFT

(SIMULATION NUMÉRIQUE DU PILONNEMENT SUR L'EAU D'UN AÉROGLISSEUR À DEUX DIMENSIONS)

M.J. Hinchey, Memorial University of Newfoundland

ABSTRACT

A simulation of a two-dimensional hovercraft is made using a numerical model based on a Navier-Stokes description of water motion, which allows for non-linear behaviour. This is combined with the equations governing heave motion of a hovercraft to obtain cavity pressure oscillations. Results are compared with previous calculations by the author using the linear Lamb oscillation model, based on the dimensions of a small experimental hovercraft. Instability onset is correctly predicted by the simulation. The modulation of the lip air flow by the water motion is shown to have a destabilizing influence at low cavity pressures. While this approach shows promise, it requires a large capacity computer, which rules out the solution of three-dimensional cases at this time.

RÉSUMÉ

Une simulation du comportement d'un aéroglisseur au-dessus de l'eau est faite à l'aide d'un modèle numérique appliqué à un véhicule à deux dimensions. Le modèle numérique s'inspire des équations de Navier-Stokes, permettant de traiter des cas non linéaires, auxquelles sont ajoutées les équations décrivant le pilonnement d'un aéroglisseur. Les résultats sont comparés à ceux obtenus précédemment par l'auteur en utilisant le modèle linéaire oscillatoire de Lamb, basé sur les dimensions d'un petit aéroglisseur expérimental. Le début de l'instabilité a été correctement calculé par le modèle. De plus, il a été démontré que la modulation du débit d'air sous le rebord de la jupe, causée par le mouvement de l'eau, résulte en un effet déstabilisateur aux basses pressions dans la cavité du coussin. Cette méthode numérique semble prometteuse, cependant le temps de calcul nécessaire, plusieurs heures sur un VAX, rend improbable son extension à des cas à trois dimensions.

NUMERICAL SIMULATION OF OVER WATER HEAVE MOTION OF 2D HOVERCRAFT

by

M.J. HINCHEY (MUN)

BACKGROUND

When a hovercraft is undergoing heave motion over water, its motion generates a pressure oscillation within its air cavity which in turn generates waves in the water surface. These waves modulate the volume of the cavity directly beneath the craft and the air flow directly beneath the skirt at the cavity lip. These in turn can modify the stability of the craft itself, mainly through an influence on the phasing of the craft motion with respect to cavity pressure. Hinchey and Sullivan [1] showed for 2D craft that the modulation of the cavity volume by the waves usually improves stability whereas the modulation of the leakage flow at the lip can have a large destabilizing influence at low cavity pressure or craft weight. They based their work on a potential flow water compliance model developed by Lamb [2]. Below, a different water compliance model is developed. It is basically a numerical simulation based on a Navier-Stokes description of the water motion. It allows one to consider nonlinear phenomena, something ignored in the previous work. It is used herein as a check on the earlier work.

MUN: Memorial University of Newfoundland

OUTLINE OF SIMULATION

A 2D hydrodynamics code, developed at the Los Alamos Scientific Laboratory [3], is used to track the water motion. The equations governing the motion are:

MOMENTUM EQNS

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right]$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - g + \nu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right]$$

CONTINUITY EQN

$$\frac{1}{\rho c^2}\frac{\partial p}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

VOLUME OF FLUID EQN

$$\frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} = 0$$

where x and y are spatial co-ordinates, t is time, u and v are velocities, p is pressure, F is a volume of fluid (VOF) function, ρ is the density of water, ν is its viscosity, c is the speed of sound in water and g is the acceleration due to gravity. The computational domain is shown in Fig. 1: the location of the hovercraft is denoted by a heavy line in the upper left hand corner of the bottom sketch. The momentum equations are used to update the velocities u and v step by step in time throughout the

domain. The continuity or conservation of mass equation allows one to update the pressure p and make corrections to u and v. The VOF equation allows one to track the water surface: F is equal to unity within the water and zero outside. The cavity pressure is applied directly to the water surface in the simulation [3]. It is taken to be uniform within the cavity region and undergo a linear fall-off to atmospheric pressure at the lip. The latter can be abrupt or gradual: in other words, it can happen over a single or several computational cells. Each governing equation is put into the form:

$$\frac{\partial A}{\partial t} = B$$

Each is then integrated numerically across a time step Δt to obtain updated values of A:

$$A(t + \Delta t) = A(t) + \Delta t\ B(t)$$

where the various derivatives in B are discretized using finite difference approximations. The details of this can be found in [3].

The equations governing the heave motion of the craft are [1]:

NETWON'S SECOND LAW

$$m \frac{d^2Z}{dt^2} = P\ S - mg$$

CONSERVATION OF MASS

$$C_p \frac{dP}{dt} = Q_{in} - Q_{out} - \frac{dV}{dt}$$

ORIFICE FLOW LAW

$$Q = C_d D\sqrt{\frac{2\Delta P}{\sigma}}$$

where m is the supported mass, Z indicates its position vertically from a rest state, P is the cavity pressure, S is the support area, Q is a volumetric flow, D is a flow area, V is the cavity volume, C_p is the cavity capacitance, C_d is a discharge coefficient and σ is the density of air. The motion of the water surface modulates V and D for the leakage flow. The craft equations are integrated numerically using a predictor-corrector procedure. At its lowest level, this is the same as the second-order Runge Kutta scheme. It is the highest order procedure consistent with the simulation of the water motion.

WATER SURFACE PROFILES AND STABILITY

HEX-5 was one of a number of small research craft developed by Fowler and his colleagues at NRC during the late seventies and early eighties. Its beam was 2.5 m and its cushion was 0.2 m deep. Hinchey and Sullivan analyzed the over water heave stability of a 2D section of HEX-5 using the water compliance model taken from Lamb [2]. They also used the water compliance model to study the water surface profiles generated when the cavity pressure was allowed to undergo a sinusoidal oscillation. Fig. 2 shows typical profiles generated for HEX-5: IN indicates a component in phase with pressure while OUT indicates a

component 90° out of phase. Fig. 3 shows profiles generated by the simulation: HOLE indicates the depth of a trough directly beneath the craft created by a hydrostatic pressure and AMP is the amplitude of the cavity pressure oscillation about the hydrostatic level. Comparison with Fig. 2 shows that there is reasonable agreement. The duration of the simulation was typically around 10 seconds and the profiles given are for the last second of this. By this time, start up transients were no longer present. During the simulation, the water was discretized typically by 20 horizontal grid lines and 250 vertical lines: about 20 of the vertical lines were in the cavity region. This was considered to be adequate for the wave lengths generated. The grid was uniform throughout except for the far right hand side where it was allowed to expand horizontally so that reflected waves from a vertical wall there did not have a chance to form. For the profiles given, the drop-off in pressure at the lip occurred across the 4 vertical lines just outside the cavity. Finally, the water depth used in simulation was 2 m. For the frequency tested, this is basically deep water.

The simulation work to date on heave stability has been very exploratory in nature and much more needs to be done to verify and extend the predictions. For example, craft disturbances used to start the simulation have so far been kept small, in an attempt to avoid nonlinear phenomena. Also, in early runs, the hydrostatic trough due

to craft weight was found to create very complex water flows near the lip and very erratic and perhaps unrealistic craft behavior. So, it has since not been allowed to form. Note that this makes the simulation more consistent with the earlier work which also ignored the trough. Finally, even with the above restrictions, runs are often computationally very expensive, sometimes taking several hours of VAX CPU time to complete, even with coarse grids and short duration times. This is a very serious drawback of the simulation. It effectively rules out 3D computations at this time.

Fig. 4 shows simulation traces for a case where the rest gap was 4.5 mm and the water motion was not allowed to influence craft heave motion so that the craft operated as if it were over land. Routh Hurwitz calculations for this case indicate that instability would occur if the cavity pressure was increased beyond 70 cm H_2O. The simulation traces are in agreement with this. To some extent, this proves that the predictor-corrector scheme adopted is adequate. The earlier work on stability suggested that volume modulation due to waves would improve stability at 70 cm H_2O. Fig. 5 shows a preliminary trace from the simulation which shows this improvement in stability. Note that the frequency of the oscillation is basically unchanged by volume modulation. This is as predicted by the earlier work. The trace shown is not overly sensitive to things such as the spatial or temporal

grid size used by the simulation or the details of the pressure variation (gradual/abrupt) near the lip. So, the improvement in stability is genuine. The earlier work also suggested that leakage flow modulation due to waves can degrade stability at low cavity pressures and make the craft undergo many stability transitions. For example, for the present geometry, it predicted a transition near 30 cm H_2O. Fig. 6 shows preliminary traces from the simulation which show such a transition. However, these traces are very sensitive to things such as the pressure variation near the lip: so more work needs to be done to confirm the trend. Note in each trace that the frequency of the oscillation is much lower than that of the overland traces. This is as predicted by the earlier work. The simulation is now being used to explore nonlinear phenomena.

REFERENCES

1. M.J. Hinchey and P.A. Sullivan, "On the Heave Stability of Hovercraft Hovering Over Water", Submitted to the Journal of Sound and Vibration, November 1988.

2. H. Lamb, "On Deep Water Waves", Proceedings of the London Mathematical Society, Series 2, Volume 2, November 1904.

3. B.D. Nichols, C.W. Hirt and R.S. Hotchkiss, "SOLA-VOF: A Solution Algorithm for Transient Fluid Flow with Multiple Free Boundaries", Los Alamos Scientific Laboratory, LA-8355, 1980.

ACKNOWLEDGEMENT

This work was funded by NSERC through Operating Grant A4955 (Hinchey).

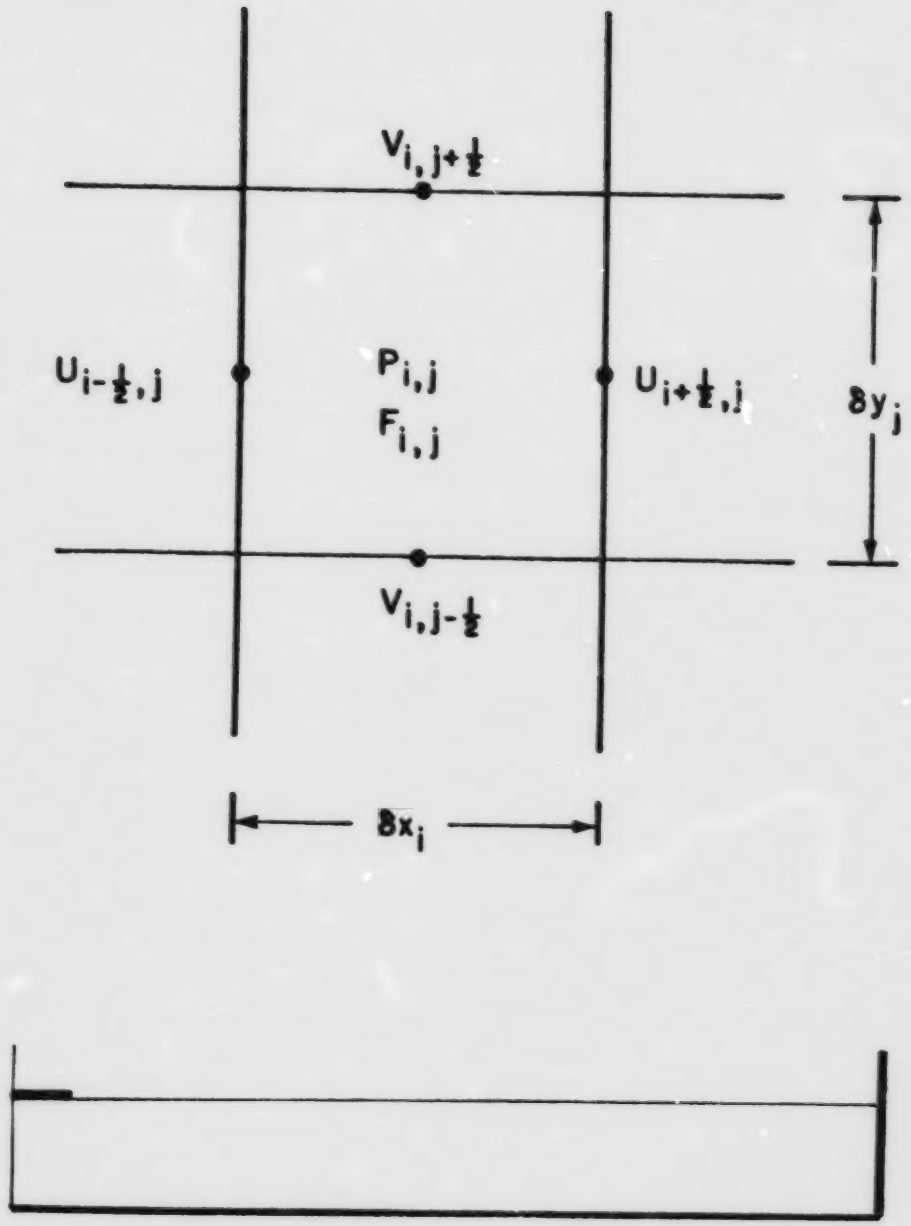


Fig. 1. Computational Domain for Hovercraft Simulation.

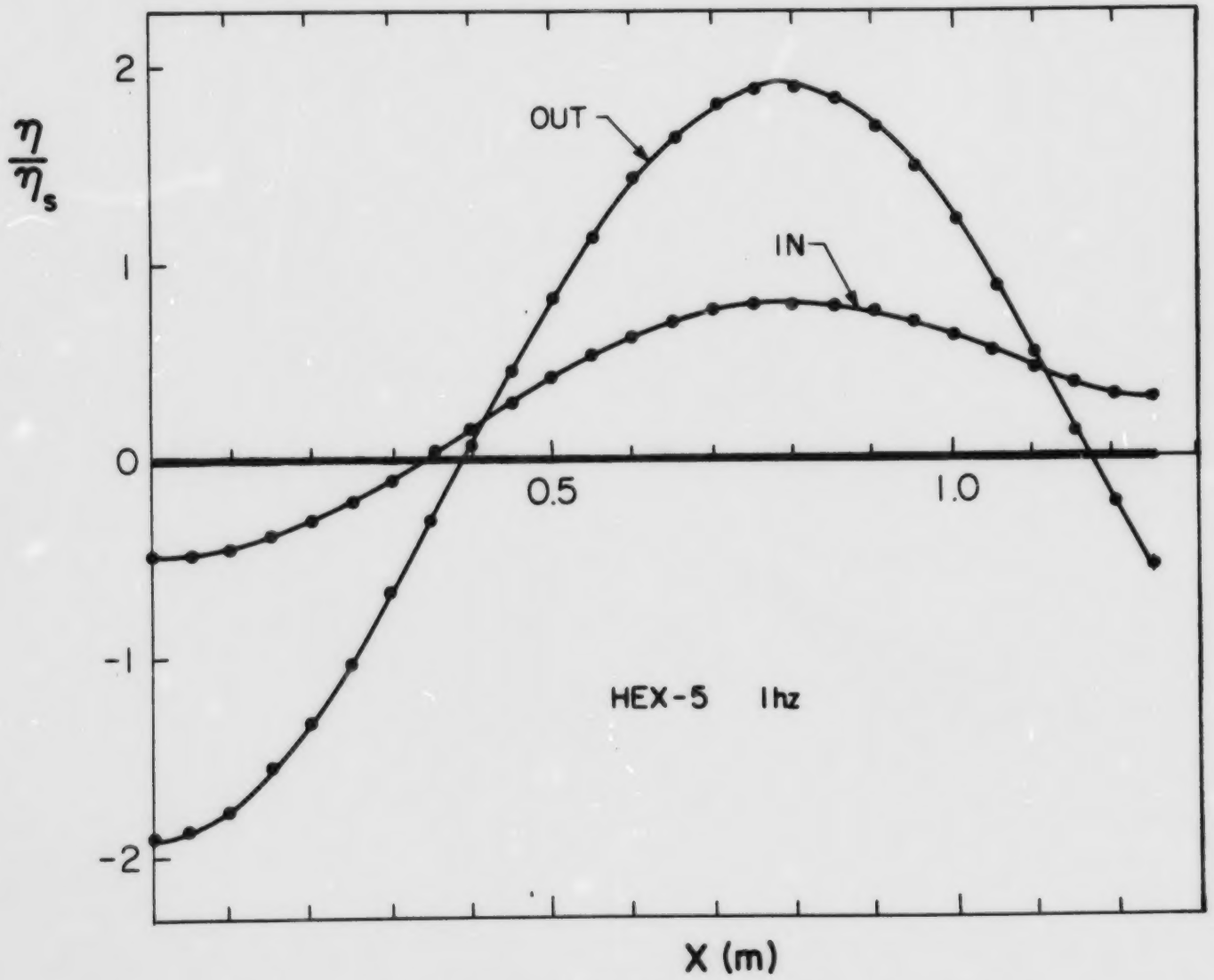


Fig. 2 Water Surface Profiles for HEX-5 from Lamb.

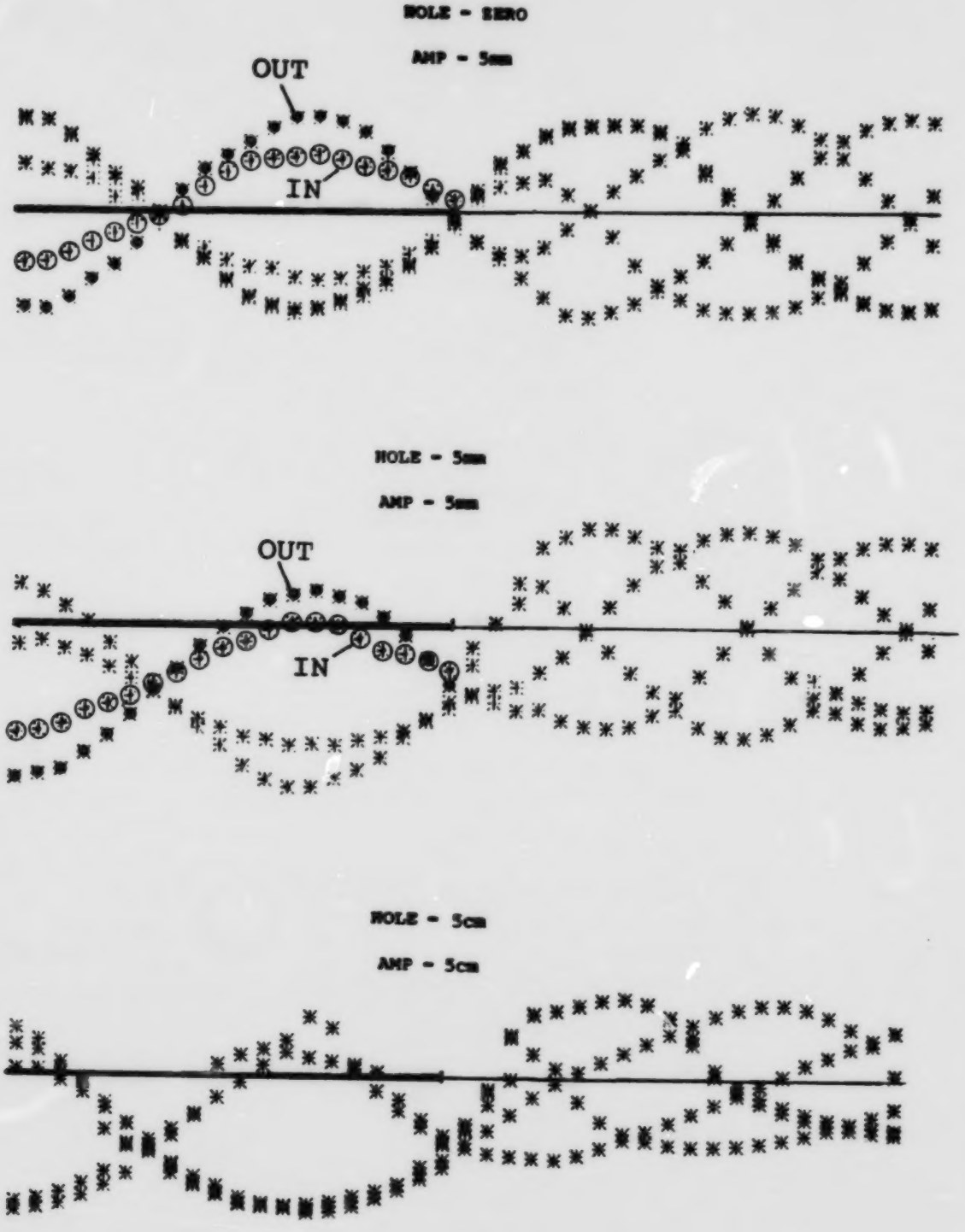
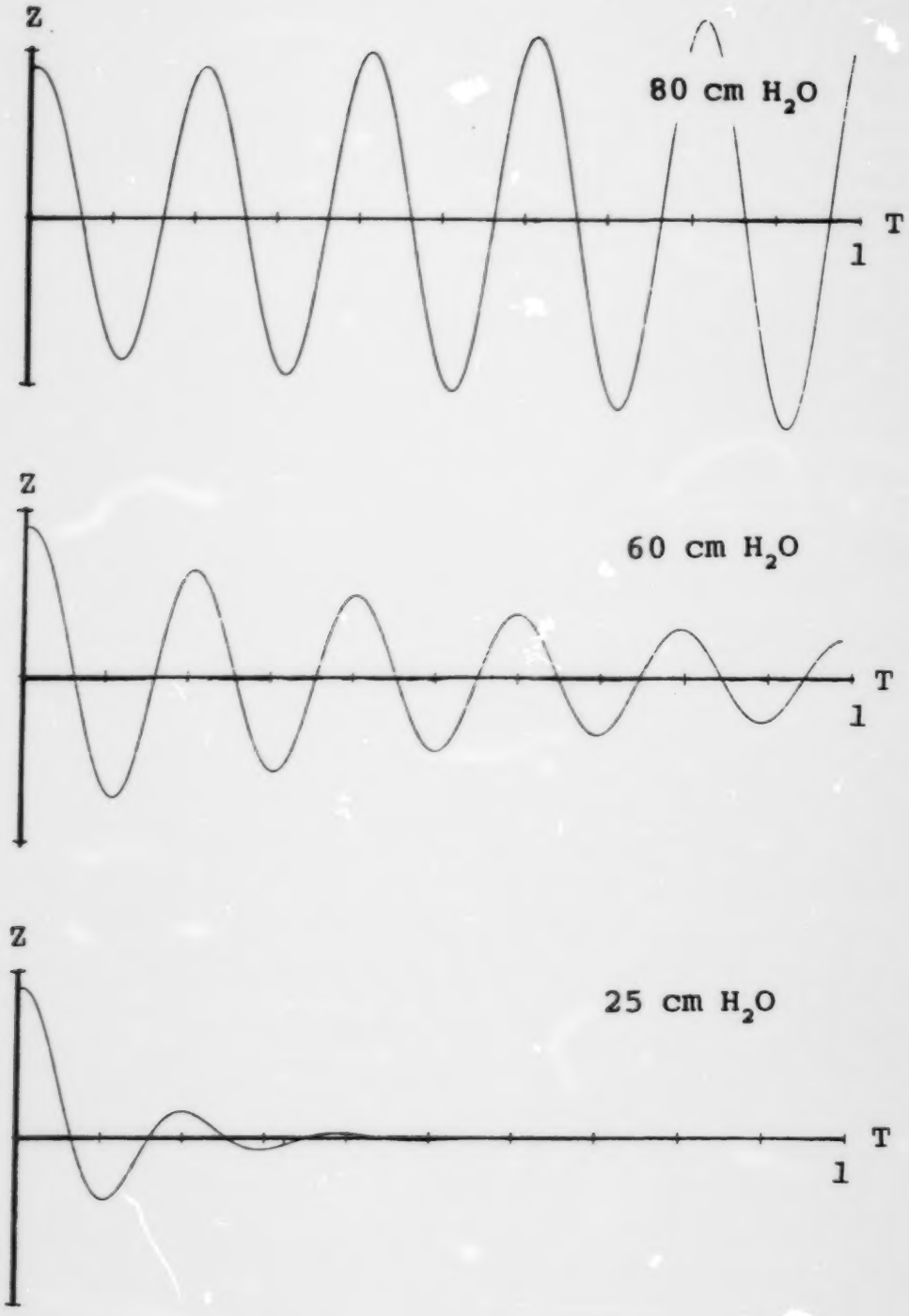


Fig. 3 Water Surface Profiles for HEX-5 from Simulation.



GAP = 4.5 mm Z_o = GAP / 100

Fig. 4 HEX-5 Overland Simulation Traces.

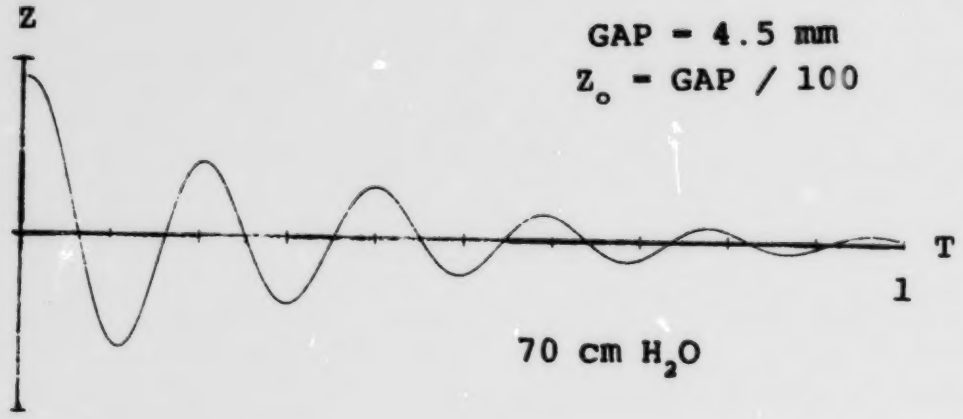


Fig. 5 HEX-5 Overwater Simulation: Cavity Volume Trace.

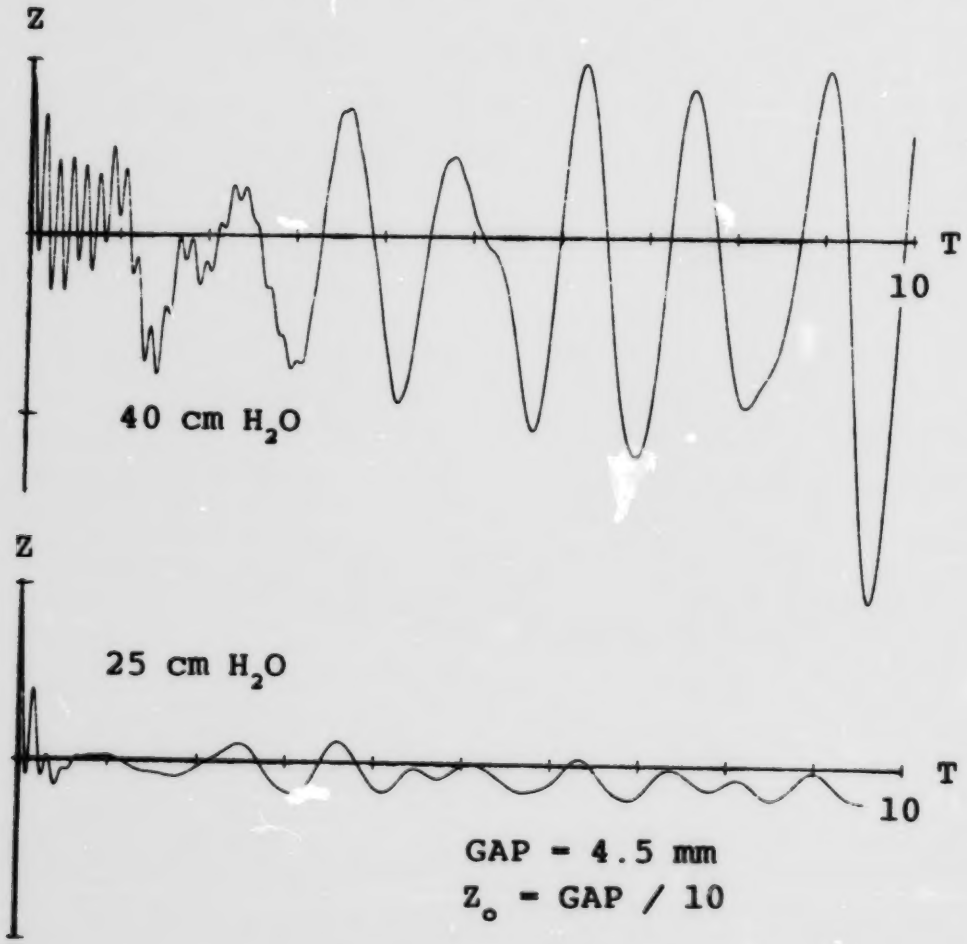


Fig. 6 HEX-5 Overwater Simulation: Leakage Flow Traces.

SOME EXPLORATORY TESTS ON CIRCULAR AND SIDEWALL ACIB CONCEPTS

(ESSAIS PRÉLIMINAIRES SUR DEUX BRISE-GLACE À COUSSIN D'AIR : L'UN CIRCULAIRE, L'AUTRE À PAROIS LATÉRALES)

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M.J. Hinchey and L. Mak, Memorial University of Newfoundland

ABSTRACT

Non-dimensional parameters are proposed for the resistance and speed of air cushion ice-breaking bows (ACIBs). Data obtained from tests on circular and sidewall ACIBs indicate that resistance is independent of ice thickness and related to the air cushion pressure. Models required higher pressure ratios (cushion pressure, expressed in terms of height of a water column, over the ice thickness) to break the model ice than the ratio that was effective with full-scale ACIBs, probably due to higher relative toughness of the model ice, allowing a higher deflection prior to rupture than the real ice.

RÉSUMÉ

Des paramètres sans dimensions sont proposés pour normaliser la résistance et la vitesse de brise-glace à coussin d'air. Des essais sur deux maquettes, circulaire et à parois latérales, indiquent que la résistance à l'avancement serait indépendante de l'épaisseur de la glace et plutôt reliée à la pression du coussin d'air. Les maquettes exigeaient des rapports de pression plus élevés que ceux observés sur les essais en vraie grandeur (le rapport de pression concerne celle du coussin d'air, exprimée en hauteur manométrique, sur l'épaisseur de la glace). Cela proviendrait du fait que la glace modèle est très épaisse, permettant une plus grande déflection avant la rupture que la glace réelle.

SOME EXPLORATORY TESTS ON CIRCULAR AND SIDEWALL ACIB CONCEPTS

by

B. COLBOURNE (IMD)

M. HINCHEY (MUN)

L. MAK (MUN)

BACKGROUND

The ability of air cushion vehicles or hovercraft to break floating ice sheets was discovered by accident. During the early seventies, the towed air cushion platform known as the ACT-100 was observed to break sheets about 1m thick during field trials near Yellowknife in the NWT [1]. Typically, the water surface directly beneath the craft was depressed below the lower edge of the sheet, and an air cavity was formed which propagated away from the craft under the sheet. The sheet failed mainly due to bending stresses set up by the weight of an unsupported or overhanging section of the sheet inside the cushion [1]. The ACT-100 was later mated with the bow of an icebreaker ship, which pushed it onto the floating sheets. On an energy consumption basis, this combination was found to be much better than the icebreaker acting alone [1]. Its resistance to forward motion was much lower, and it broke ice at a faster rate. More recent operations have shown

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ACIB: Air Cushion Icebreaker Bow
IMD: Institute for Marine Dynamics, Newfoundland
MUN: Memorial University of Newfoundland

that a tugboat is just as effective as a conventional icebreaker in this role. Unlike conventional icebreakers, the hovercraft/ship combination does little damage to port facilities, mainly because it exerts insignificant forces in the plane of a sheet. However, operations to date have shown that hovercraft cannot break ridged pack ice of the type and size that occurs in the Arctic.

CIRCULAR/SIDEWALL CONCEPTS

In 1984, two new craft were proposed. The rationale for these can be found in [2]. One was a circular or round planform craft designed for operation in inland waters with an ability to break uniform ice sheets about 1 m thick at full scale; the other was a sidewall craft designed for mid-Arctic operation in regions where ice sheets, with moderate ridging, are typically about 2 m thick. Both craft used a simple kneeless segment skirt, to simplify maintenance. Both used drag sheets to keep the skirt free from ice blockage, and both used a spray apron to minimize spray-ice build-up on the super-structure. The craft are shown schematically in Fig. 1.

EXPLORATORY WORK AT IMD

Models of the new craft were constructed at MUN at a geometric scale of 1:20 and tested in the Ice Tank at IMD [3]. For this, the sidewall craft was first scaled down to the size of the round craft. Pictures of the models

are shown in Fig. 2. Each had a support structure constructed from plywood approximately 18 mm thick and aluminum plate approximately 3 mm thick. Each used a kneeless segment skirt made from a light nylon fabric approximately 0.25 mm thick, supplied by UNITED SAILWORKS (Newfoundland). Neither model used drag sheets or a spray apron. It was felt that these were unnecessary complications at model scale. It was also felt that a skirt at the rear of the sidewall craft was unnecessary: an inclined flat plate was used instead in the model. The sidewall craft used a total of fourteen segments while the round craft used sixty. The size of the segments was the same for each craft. For the exploratory work, all model motions, except for surge, were suppressed. It was hoped that this would simplify data interpretation. Each model was towed over a number of sheets, each with thickness approximately uniform throughout, at a number of constant speeds, and its resistance to forward motion in each case was measured with a load cell. Cushion pressure and flow were also measured, and video cameras were used to record the icebreaking action. A vortex blower was used to supply cushion air. Standard procedures were used to grow ice sheets with scaled mechanical properties [3].

Some preliminary tests with the circular model on intact and pre-broken sheets showed that the breaking component of resistance is insignificant, at least at low speed. This suggests that ice properties such as strength

have at best only a minor influence, which implies that scaling laws can ignore ice properties. Resistance to forward motion F can be nondimensionalized in a number of ways. In hydrodynamics, it is customary to nondimensionalize it by a force equal to a pressure times an area. This is the approach taken here. The dynamic head due to craft motion gives a pressure. However, for ACIB work, the cushion pressure P is probably more appropriate and is used herein. For an area, one could use D^2, where D is the width of the cushion, which for both models tested at IMD was approximately 0.91 m. This area is a measure of the cushion footprint and so PD^2 would be a measure of the craft weight. So, resistance would in this case be given relative to the craft weight: $CF = F/PD^2$. To some extent, an ACIB acts like a water plow with an area given approximately by HD, where $H = P/\rho g$ is the depth of a trough formed by hydrostatic pressure, ρ is the density of water and g is the acceleration due to gravity. The cushion pressure acts over this area to give the force PHD. Resistance as a fraction of this force is CF = F/PHD. The present data suggest that this is a better non-dimensional representation of resistance. One could present the forward speed U nondimensionally as a Froude Number: $CS = U/\sqrt{gD}$. However, in earlier work [4], the propagation speed of the air cavity under the sheet was found to be given approximately by $U_B = \sqrt{1.3\ g\Delta h}$, where Δh is the height of the cavity. Using this speed instead to

nondimensionalize U gives CS = U/U_B. The present data suggest that this CS is more appropriate. Below CF = F/PHD and CS = U/U_B are used. Nondimensional representations of cushion pressure and flow were also developed. For cushion pressure, the thickness of ice corresponding to the cushion pressure was nondimensionalized by the sheet thickness itself: (CH = $P/\sigma gh$ where σ is the density of ice and h is the sheet thickness). Each CH value quoted herein is a run average. The cushion flow Q was non-dimensionalized by the flow $Q_o = U_o D^2$, where from Bernoulli $U_o = \sqrt{2P/\epsilon}$ where ϵ is the density of air: ($CQ = Q/Q_o$).

Fig. 3 shows nondimensional resistance data for the round model generated during intact and pre-broken sheet runs over a 40 mm thick sheet. As mentioned previously, the close agreement suggests that the breaking component of resistance is insignificant. Surprisingly, the resistance curve for the pre-broken sheet is slightly higher than the intact sheet curve. Observations of video records showed that this is due, at least in part, to craft-ice contact caused by a vertical rotation of the broken ice pieces as they entered the cushion. Fig. 4 is for a 30 mm thick sheet and shows that craft with larger CH generate slightly larger CF. Video records show they also have greater ice breaking action and more craft-ice contact. The larger CF is probably caused by this. Recall that for a given sheet a larger CH implies a deeper and faster moving cavity beneath the sheet. Fig. 5 shows that

data obtained from sheets, each with a different thickness but with approximately the same CH, collapse approximately to the same line. In addition, it shows that the present data are in agreement with tank data obtained by ARCTEC for a rectangular planform model having approximately the same CH and D [5].

Fig. 6 shows intact and pre-broken sheet data for the sidewall model. To generate this data, channels in the sheets for the sidewalls were precut so the resistance penalty due to the normal shearing action of the walls was not present. Fig. 7 shows this resistance penalty. Like Fig. 3, Fig. 6 shows that the resistance for intact sheets is typically lower than that for pre-broken sheets. It also shows that the difference in intact resistance for the two thicknesses tested is insignificant. Fig. 7 shows that for total resistance there is a transition at CS near unity. Also, when the sidewall penalty is subtracted out, the remaining resistance seems to have an upper limit slightly above unity. It appears that there the plow mechanism is fully active. The extra resistance beyond unity is probably due to friction.

A comparison of sidewall model data with that of the round model shows that resistance levels for both models are similar, provided the resistance penalty for the sidewall model is subtracted from its data and the CH values are approximately the same. For a given CH, CQ for the sidewall model was usually around half the CQ for the

round model. This implies that the sidewall craft uses less power to generate its cushion: so the resistance penalty is counteracted to some extent.

It should be noted that the field CH needed to break ice is usually around 1.1, which is much lower than that needed by the tank models. ARCTEC observed a similar phenomenon in their tank data. This is probably due to tank ice being much tougher than field ice, partly because it has fewer imperfections. During operation of the round model at the field CH level, the ice could be seen to follow the depressed water surface, and an air cavity was not formed under the sheet, even when on the basis of CH it was to be expected.

The data set obtained in the present exploratory work is quite small. Not all of it is reported herein. Some more can be found in [6]. A much larger set would be needed to confirm the scaling laws and fully understand the resistance mechanisms. Finally, in some high speed runs, a transition to a high resistance wave mode of ice breaking was observed in which large amplitude flexural-gravity waves were generated by the motion over the sheet [7,8]. This and the low speed mode will soon be explored in greater detail at IMD and MUN.

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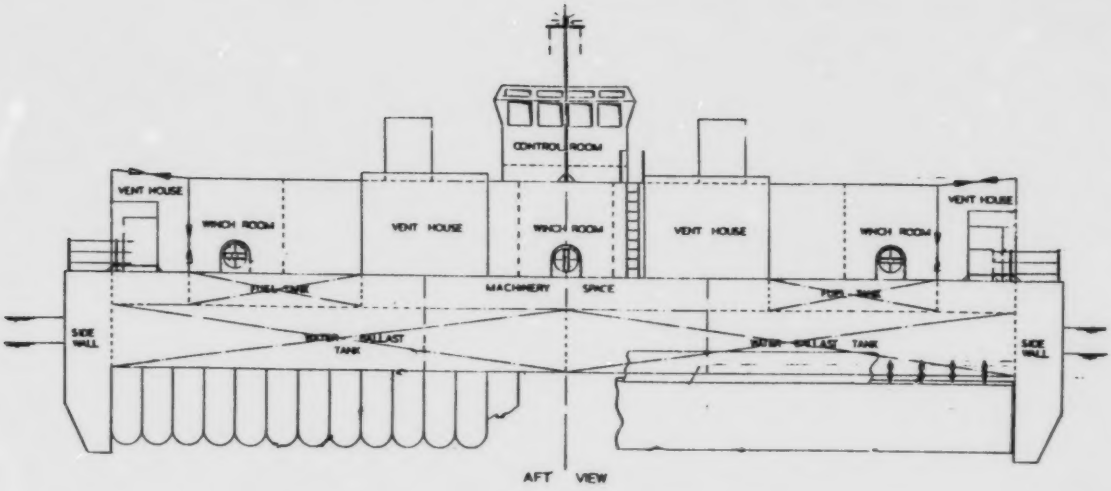
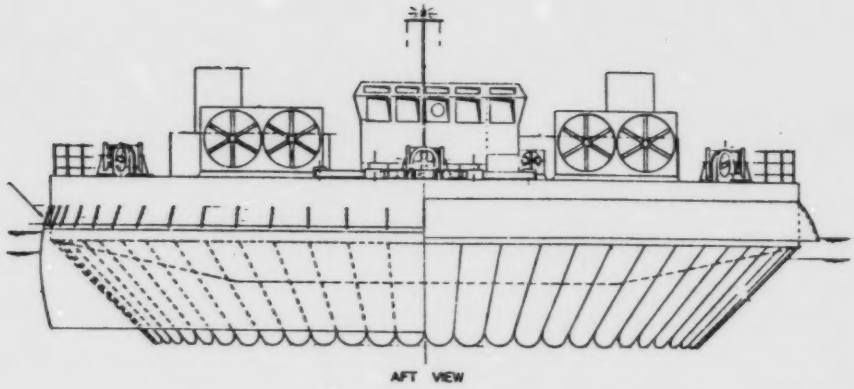
ACKNOWLEDGEMENTS

The models were constructed by Bill Burke, Jim Andrews and others at MUN. The skirts were sewn into shape by Jane Hinchey. The tests were conducted with the help of Spence Butt, Terry Lindstrom, Brian Hill and others at IMD. We appreciate very much the efforts of these people on our behalf. The work was supported financially by IMD and by NSERC through Operating Grant A4955 (Hinchey). Finally, we wish to thank the Director of IMD, Norm Jeffrey, for his encouragement.



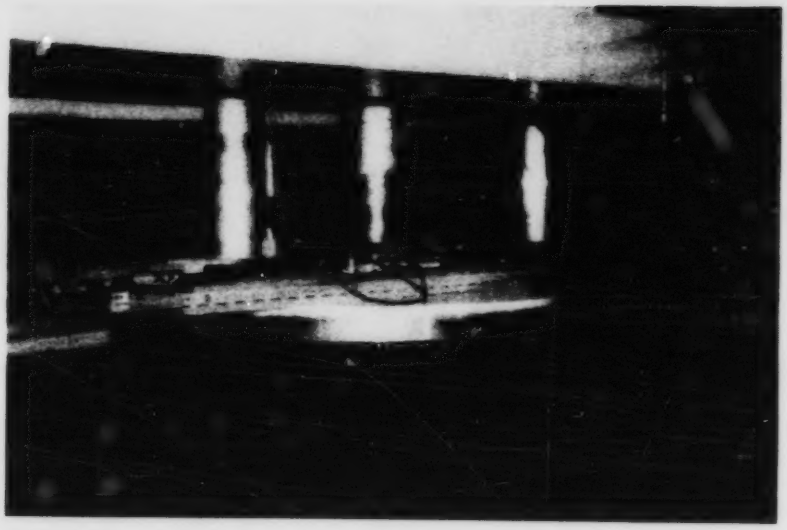
SIDEWALL MODEL



ROUND MODEL

Fig. 1 Schematics of Circular and Sidewall ACIB Craft.

SIDEWALL MODEL



ROUND MODEL

Fig. 2 IMD ACIB Craft.

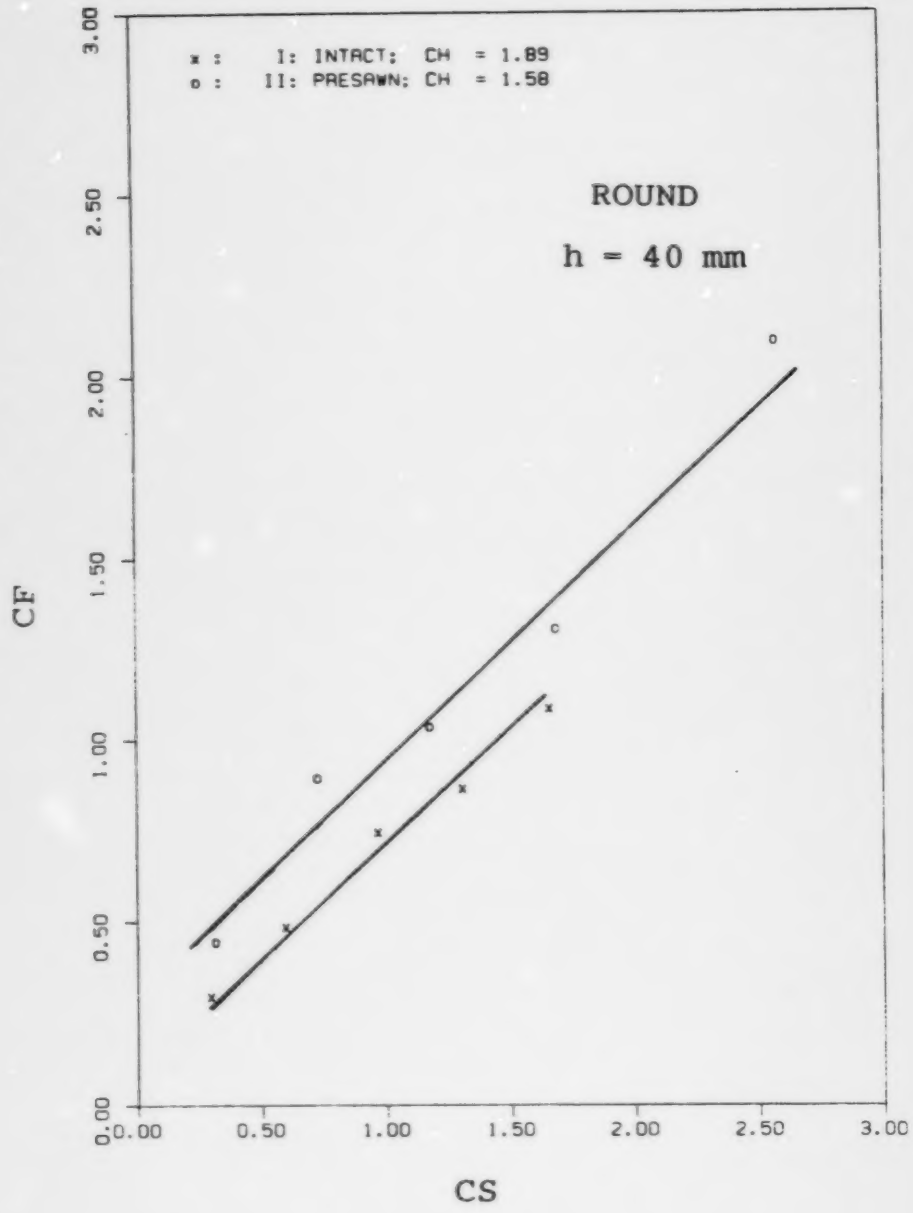


Fig. 3 Intact and Pre-broken Sheet Resistance Data for Round Model.

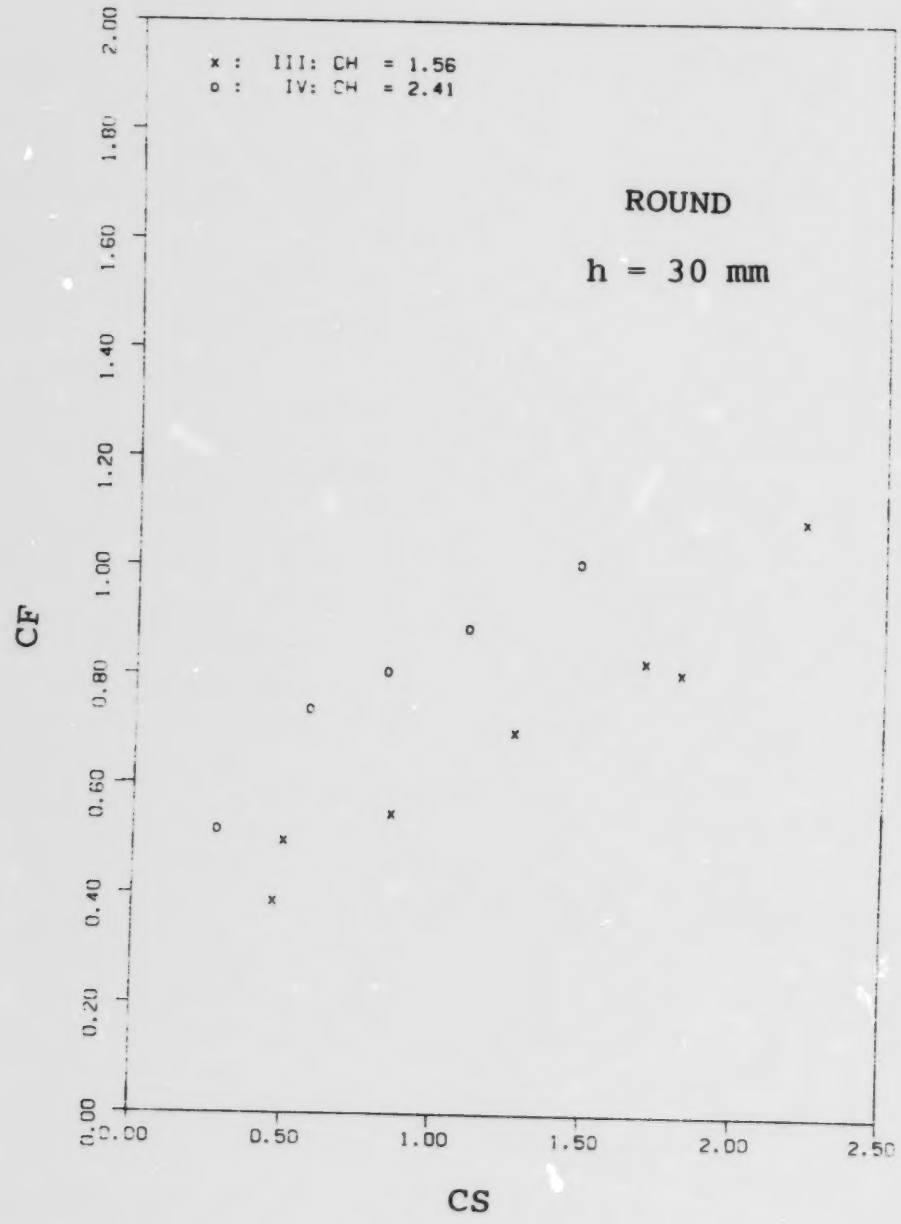


Fig. 4 Resistance Data for Round Model: CH Trend.

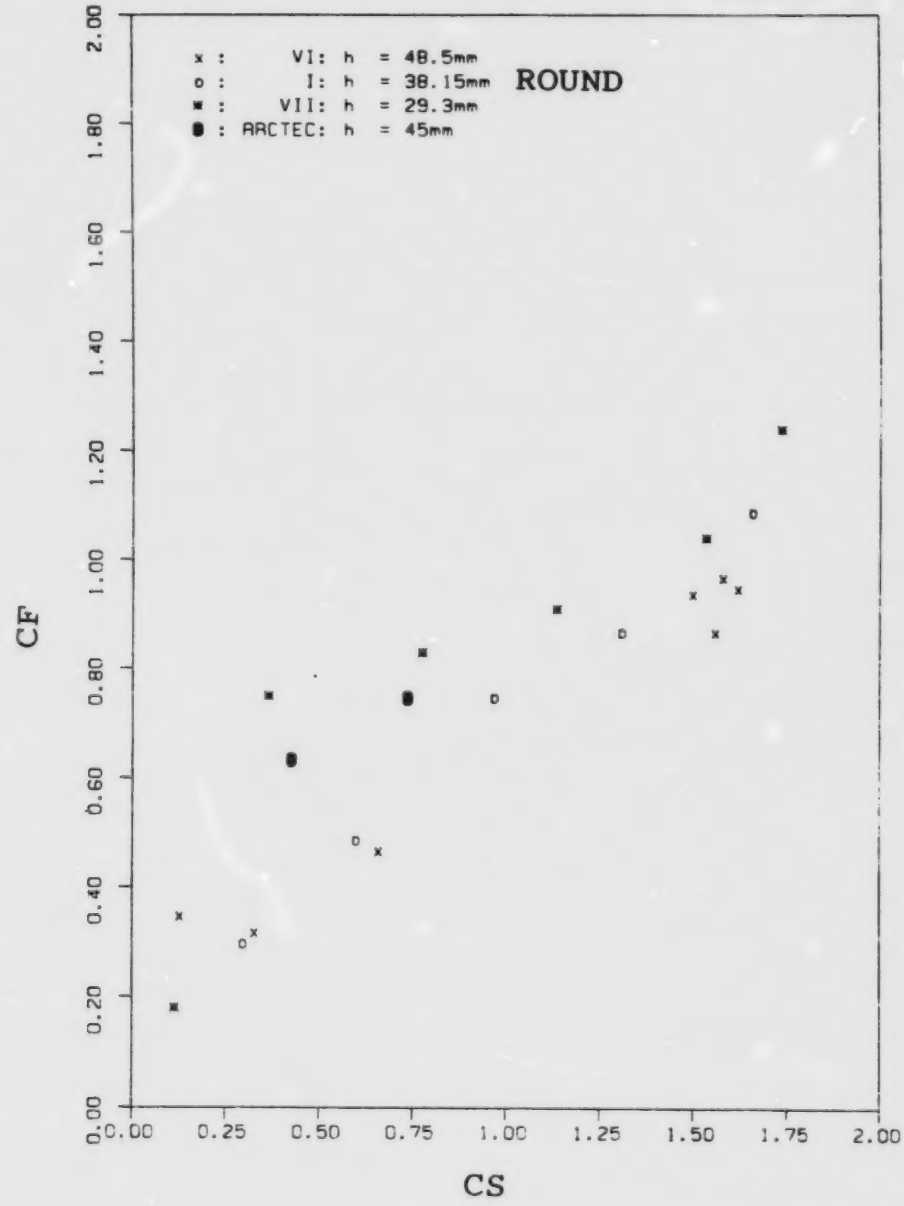
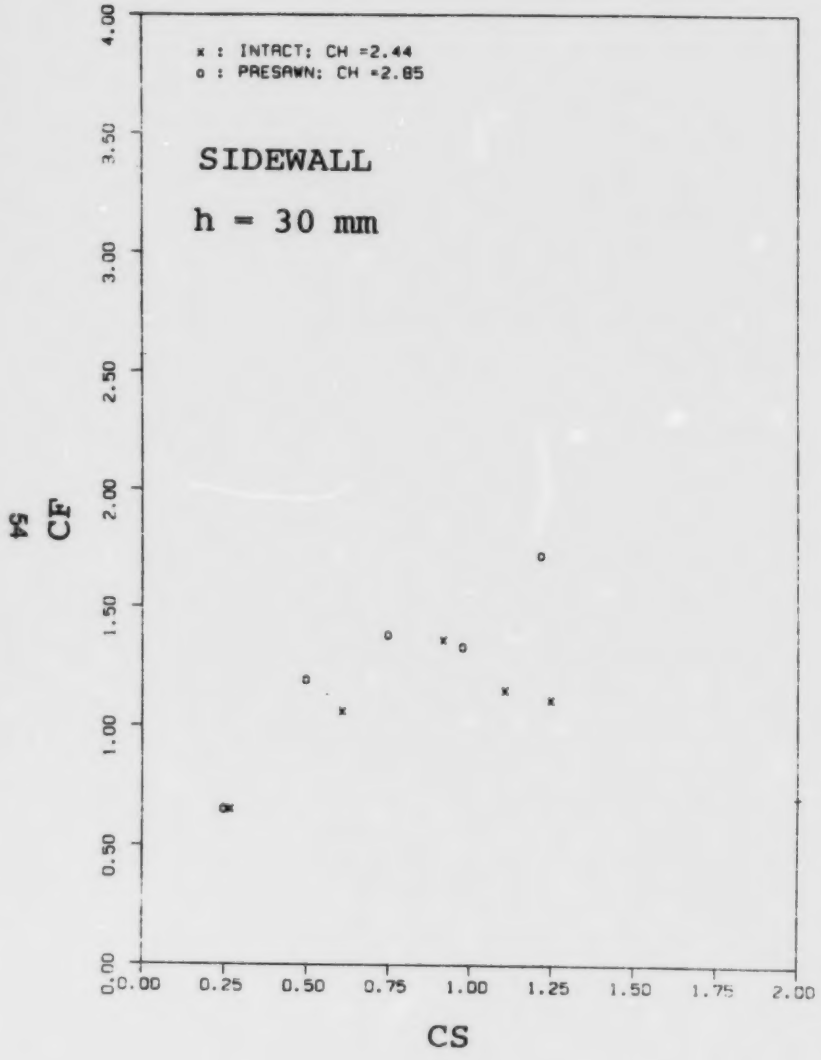


Fig. 5 Resistance Data for Round Model from Sheets with Different Thickness.



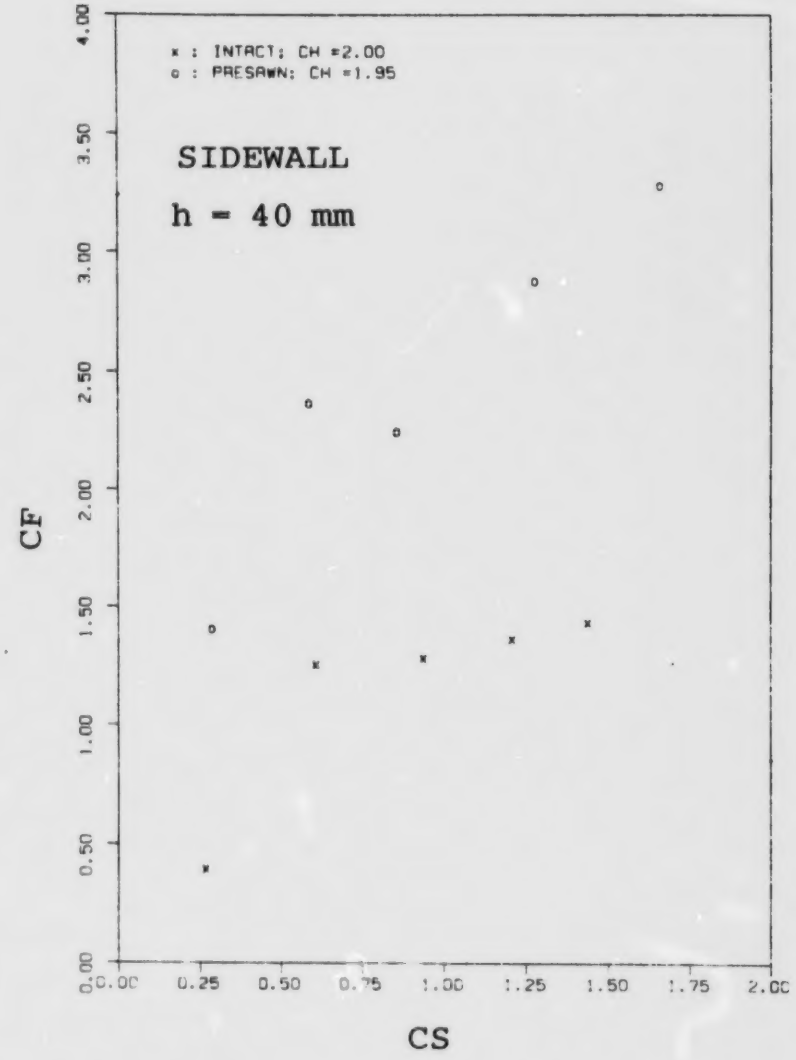
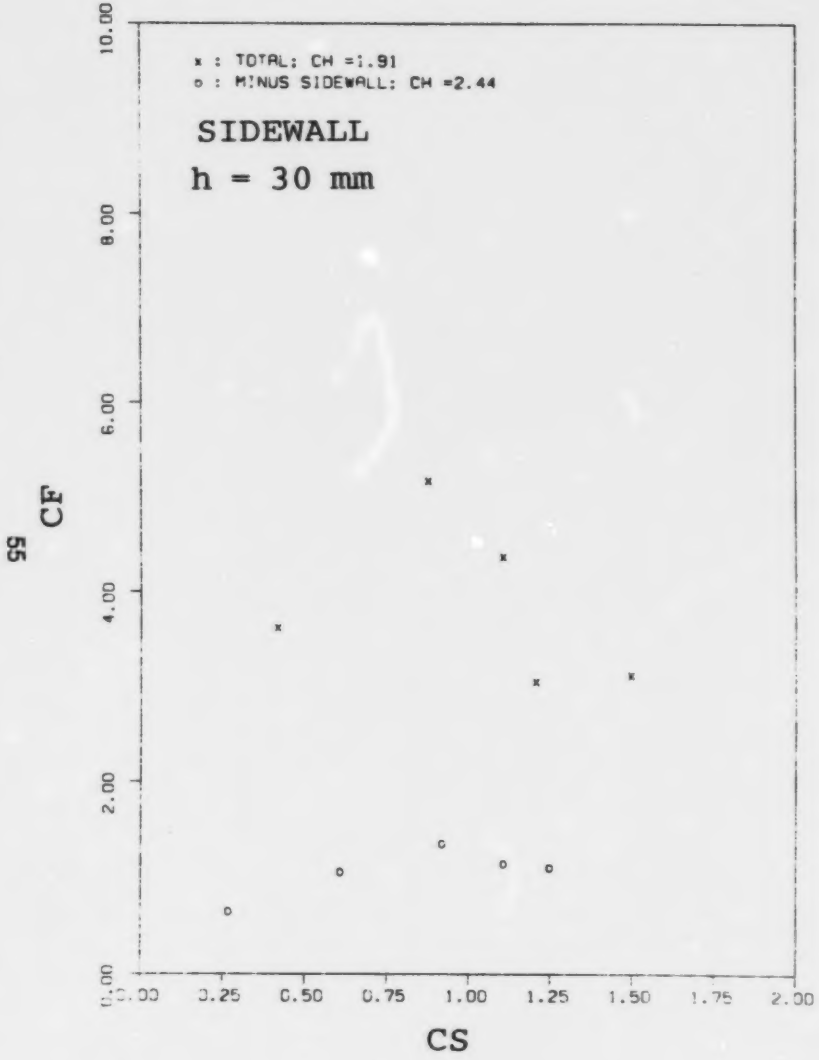


Fig. 6 Intact and Pre-broken Sheet Resistance Data for Sidewall Model.



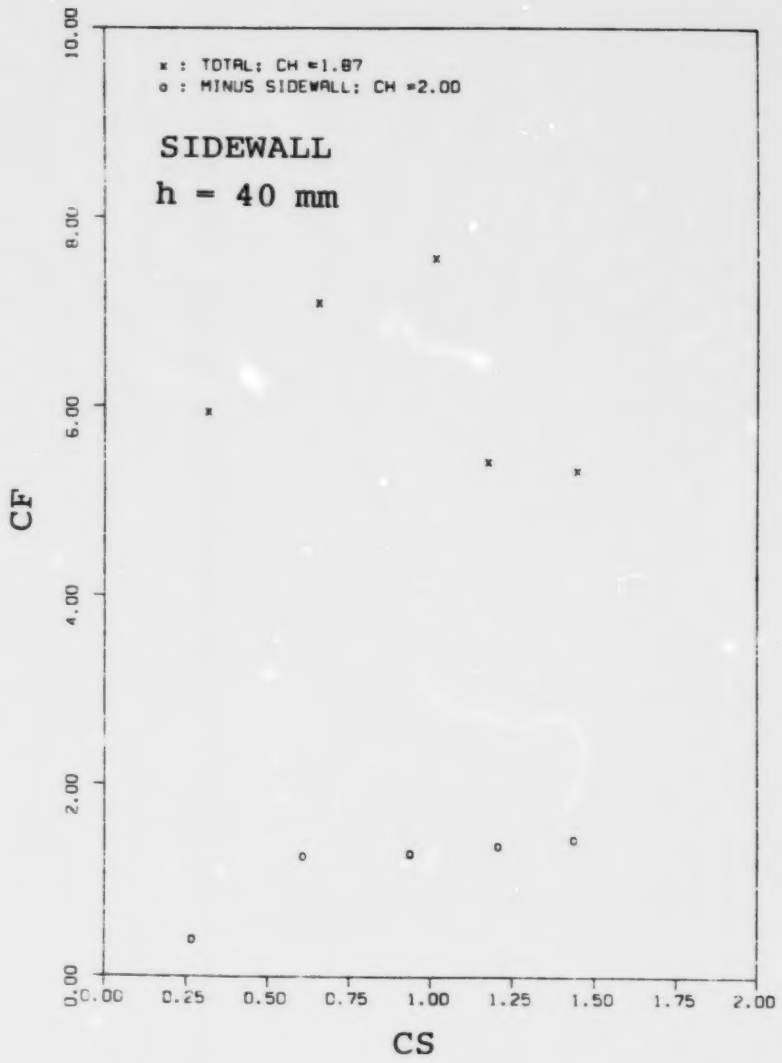


Fig. 7 Resistance Penalty due to Sidewalls.

COLD WEATHER OPERATIONS

EXPLOITATION PAR TEMPS FROID

HOVERCRAFT OPERATIONS IN ANTARCTICA
(EXPLOITATION D'AÉROGLISSEURS DANS L'ANTARCTIQUE)

J. Stephen Dibbern, U.S. Army Foreign Science and Technology Center

ABSTRACT

The use of transportation equipment in Antarctica is reviewed and the niche for air cushion vehicles (ACVs) is defined. A review is made of early trials in northern regions and of initial use of ACVs in Antarctica by New Zealand and Japan. The successful use of "Tiger 4" ACVs by the British Antarctic Survey and of the Hoversystem "Husky 1500" by the U.S. National Science Foundation indicates that ACVs are now ready for introduction in the world's harshest environment.

RÉSUMÉ

L'auteur fait une revue des moyens de transport utilisés dans l'Antarctique et y définit le domaine d'utilisation des aéroglisseurs. L'exploitation des aéroglisseurs dans les régions nordiques, leurs premières utilisations dans l'Antarctique par la Nouvelle-Zélande et le Japon y sont décrites. Le succès obtenu par le British Antarctic Survey avec le Tiger 4 et celle du Husky 1500 par la U.S. National Science Foundation, indique que les véhicules à coussin d'air sont maintenant prêts à faire face au pire environnement climatique de la planète.

Hovercraft Operations in Antarctica

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1.What Else?

The question is, "What else can do the job?" In Antarctica that means a collection of tracked and in some cases wheeled vehicles and of course helicopters. Modern ACVs offer a number of advantages over other transport means during certain times of the year and for certain tasks, but not for everything.

a.Tracks

Tracked vehicles have several drawbacks compared to the ACV. First, they are usually slow by comparison. The faster they are the lower the payload such as with snowmobiles. They are not always as safe as you would wish, particularly over floating ice. They offer a rough ride by comparison and sometimes damage not only scientific specimens but the crews as well. What they can do is go up hills and navigate rough surfaces, neither of which the ACV likes to do. They are also easier to learn to operate.

b.Helicopters

Helicopters on the other hand are extremely difficult to train for both operator and for maintenance which leads to the rather extreme operating costs which are associated with the otherwise ideal machines. Since most are turbine powered they are both short legged and expensive to feed.

c.Tasks

The tasks that have been explored for the ACV so far include; transport of scientific personnel and their supplies and specimens (which are sometimes very fragile) over sea ice and over ice shelves in both the Ross Sea along the Antarctic Peninsula and in East Antarctica. The American program has also included the support of field camps with fuel and supplies as well as the transport of service technicians for remotely sighted equipment. So basically it is scientific and logistic support.

d.Terrain

The terrain (since ACVs don't like hills) is flat; sea ice and ice shelves please, and avoid the pressure ridges! In all over ice applications so far, ice ridges have created the biggest obstacles. The flat ice surfaces allow for very high speeds and heavy payloads but ridging and the need to navigate around it can slow things down or even deny certain areas. Sever weather including high winds, low temperatures, low visibility and snow accumulation add to the problems of operations.

2.Hovercraft on Ice

ACV operations over ice are certainly nothing new since some of the very earliest craft were developed for operations on ice such as Levkov's vehicles in the USSR and Kaario's in Finland. It was not until the first practical craft were produced in the United Kingdom that serious over ice operations began.

a.SR.N5-6

Some of these early operations included SR.N5 and 6 craft which went on trials at such places as Churchill on Hudson Bay in the 1960's and the Northern Transportation Company Ltd and Pacific Hovercraft which operated them in the MacKenzie Delta and the North Slope of Alaska respectively. Meanwhile the British Army was operating their SR.N6's over fjord ice very successfully in Northern Norway. Not to be left out, the US Coast Guard and Navy operated SK-5's at Point Barrow. By the early 70's the US Army was testing an SK-5 on Lake Superior during the winter as well as later at Fort Greeley in the Alaskan interior.

b.Voyageur

The operation by both CAPS and NTCL of the Bell Canada Voyageur was a real milestone for ACV Northern commercial ACV technology. These machines along with an American program on Alaska's North Slope offered the first real demonstration of commercial potential over ice and snow.

The Canadian Coast Guards workhorse Voyageur however, was the real star of the show. The Coast Guard operated their machine over ice in the Great Lakes and in the St. Lawrence River. They were responsible for the development of the high speed icebreaking techniques which they continue to use today with their AP.1-88 the "Waban Aki".

c.Barges

Air cushion barges were used in their earliest stages in polar areas, particularly in the Soviet Union where they continue to be used. The Soviets have made extensive use of barges in their oil extraction industries and as lighterage on their shipping routes across Arctic Russia.

Meanwhile in Canada barges such as the ACT 100 were being developed and the phenomenon of air cushion icebreaking was being discovered- but that is yet another story! In some cases the icebreaking potential was a problem since the rivers in Alaska and the Northwest Territories are used as highways during the winter. This was a problem faced by the D-PAAC when it was used as a self-propelled cargo platform in Alaska.

Other countries such as Finland, Japan and the United Kingdom have operated barges which were designed for cold weather or over ice operations.

3.Antarctic ACVs

a.Sir Vivian Fuchs

Soon after the Churchill trials in the 1960's, Sir Vivian Fuchs, the celebrated Antarctic explorer and by then Director of the British Antarctic Survey, wrote an article for the Polar Record outlining the possibilities of using ACVs in polar regions. The conclusion was that while the theory held great promise, the hardware was not yet up to snuff. (Sound familiar?) The gas turbine in particular was very thirsty.

b.New Zealand Antarctic Research Program

Sometime soon after Fuchs' paper (and here frankly I am at a loss, since much of this is hearsay) it appears that the New

Zealand Antarctic Research Program sent a small inflatable ACV (probably an early Mike Pinder machine) to McMurdo Sound. According to the story told at their base it had three motorcycle engines and was a disaster! Too primitive and fragile for a harsh climate and too small (four seats) for its perceived tasks.

c.Japanese Antarctic Research Expedition

By 1980 it fell to the Japanese to inaugurate the first substantial ACV operation on the Antarctic continent. Mitsui built a machine for the Japanese Antarctic Research Expedition to be used at their base in East Antarctica. This program was reported on by Professor Murao at the meeting several years ago, but the bottom line is that the machine worked (It was gasoline powered) but that it required trained operators and was only considered a prototype of things to come. It was used to transport scientists on sea ice and as a logistics craft from the ship which because of ice conditions could not approach the base. It appears to have been used for either one or two seasons. To date no more has been heard from any follow-up.

4.British Antarctic Survey

a.Problem

Dr. Malcolm Hole is a geologist who works as a field investigator for the British Antarctic Survey (BAS). He was involved in an attempt to do a geological reconnaissance of a series of Nunataks or isolated volcanic island peaks protruding through the Larsen Ice Shelf. The plan was to fly two snowmobiles in a ski equipped Twin Otter the 500 kilometers from the main BAS base at Rothera on the west side of the Antarctic Peninsula to the vicinity of the geological survey on the Larsen Ice Shelf to the east. As the Twin Otter landed the pilot realized that the skis were sinking into waterlogged snow and that large areas of the Ice Shelf were covered with melt water. Dr. Hole's program was set back for a year and he began to search for a means to travel on the water soaked surfaces.

b.Solution

According to Dr. Hole the idea of using a hovercraft surfaced first as a joke in the Rothera bar one evening. In fact, the more they though about it the more sense it made. But the machine had to be small enough to fit into a Twin Otter which is the only aircraft currently in the BAS inventory. The craft selected was the RTK (now Air Vehicles Ltd) Tiger 4 which is one of Mike Pinder's inflatable designs. The hovercraft could be flown to the sight and assembled (inflated) on the spot. Two machines were bought and shipped to the Antarctic for the 1987 season. Although the Tiger 4 is a nominal four-seater, Dr. Hole and his field assistant used the two craft as single seaters. The requirement for safety and survival gear, additional fuel, geological specimens (Rocks are heavy!!) meant that not only was each Tiger 4 reduced to one man but that unlike snowmobile field parties which move men and camps from place to place, the camp had to remain in one spot and they used the hovercrafts speed to transport them out each day to a new area for "geologizing". The two small machines ventured

as far as 92 kilometers out from base each day and they successfully completed all of what they set out to do in 61 field days. By the way, 18 of those days were spent laid up by weather. They used similar weather limits to those that they would have used for the snowmobiles since the limitation was more on work at the sights than on travel. Also 16 days were spent waiting for the "Twin Otter" to come and pick them up. The biggest modification to the craft was the use of a slightly larger Rotax engine, not for extra horsepower but because it is the same engine that all of BAS's 115 snowmobiles use-- they have lots of spares and experience with that particular engine. They were user operated with a minimum of training and a few trial runs on the sea ice around Rothera. At the end of the program the combination lift/propulsion fans were falling apart (one did disintegrate). They were returned to Air Vehicles who have made several modifications and as we speak the two craft are on their way back to Antarctica for use again, probably by biologists on the shifting sea ice around the base this time. So BAS has a new tool, one which they consider to have been very successful.

5. US Antarctic Program

a.Background

The US ACV program's genesis has been fairly well report over the last few years at this meeting by both Harvey Cook and myself. Suffice to say that several years ago studies of the US Antarctic Program's needs for transportation on and around McMurdo Sound revealed a need for a medium sized ACV for use there. The National Science Foundation, through its contractor ITT Antarctic Services, Inc contracted for a hovercraft from Hoversystems, Inc. It was delivery by the yearly resupply ship in February of 1987.

b.Machine

The "Husky" 1500 is powered by a Duetz air cooled diesel engine and has a nominal payload of 1500 kg. In fact, because of extensive modification to the original design the payload has been reduced. The modifications include; a strengthened under hull to allow for ice impacting, full length skids under the craft, extensive crew heating and engine preheating systems, cold compound natural rubber seals and skirts, and a crane designed to lift a 55 gallon (US) oil drum or a snowmobile in or out of the cargo bay.

c.Performance

Most of the details of the craft have already been reported, but it has now completed its first full year of operations and we thought that you might be interested in what it accomplished. First, the bottom line, it did what was expected of it and more. Second, there were problems, but most have been solved and several are currently being fixed. The Husky's design speed is 35 knots which was achieved over ice at 20% below the normal engine speed. Top speeds of over 50 knots were attained and operations were carried out in up to 40 knot winds. A deficiency which became obvious was the need for increased braking. Skirt drag was minimal on ice and snow surfaces and to create enough drag to slow the craft the lift had to be so drastically reduced that solid obstacle

impact became unacceptable. The result was that the crews did a lot of pirouetting to keep speed under control which itself wasted time and reduced block speeds. A reversing propeller is being considered for retrofit to the craft this season.

d.Operations

During its first full year of operations the Husky ran for 300 hours and carried scientists and supplies up to 200 kilometers out onto the Ross Ice Shelf. It operated North of McMurdo Station across the Erebus Glacier Tongue to Cape Evans on Ross Island and as far as New Harbor on the Victoria Land coast. On one occasion the machine remained in the field overnight with the field party that it was sent to support. The scientists used it to haul biological sampling nets and traps, do surveys of animal populations, as a skin diving platform (the divers changing in the comfort of the cabin) and using the onboard crane actually using the craft to pull up instruments from the sea bottom. Support activities included Search and Rescue duty, hauling fuel and supplies to remote field camps, delivery of service technicians to remote equipment, and some demonstration trips. This last function was probably the most productive since few knew what the ACVs capabilities were. The result is that this year the National Science Foundation is flooded with requests from its grantees for the use of the machine.

e.Future

Although the possible modification to instal a reversing propeller is a major one, still the program is considered a startling success. Further modifications have been purchased for a planned deployment onto the Polar Plateau in support of various surveys. Plans call for the machine to be flown via ski equipped C-130 to the South Pole and tested there. The most important aspect of the future is that the craft has proven its efficiency and utility to the scientific community which is asking for more time on the craft than the single machine it can provide. Also, with air cushion technology a better known commodity to the Antarctic community, there are other ACV oriented ideas being discussed for even larger future projects.

6. Summary

Although ACV operations over ice and in polar areas is not a particularly new idea, their successful use in Antarctica is a relatively recent development. Beyond the earlier experiments by New Zealand and the Japanese, the British and American programs illustrate the successful introduction of two distinctly different types of operation. In 1966 Fuchs felt that the hovercraft of the time was not yet ready for introduction into the worlds harshest environment, it should be clear that the craft of today are.

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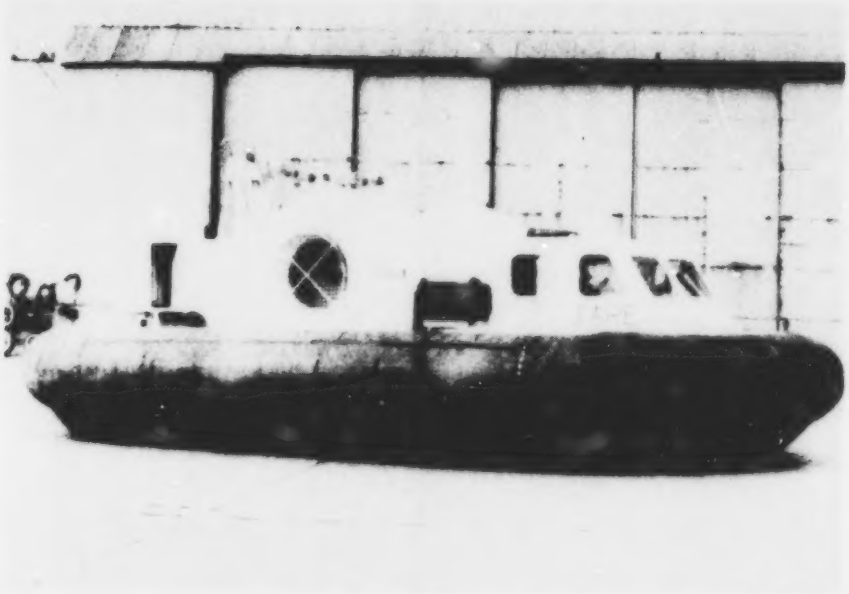
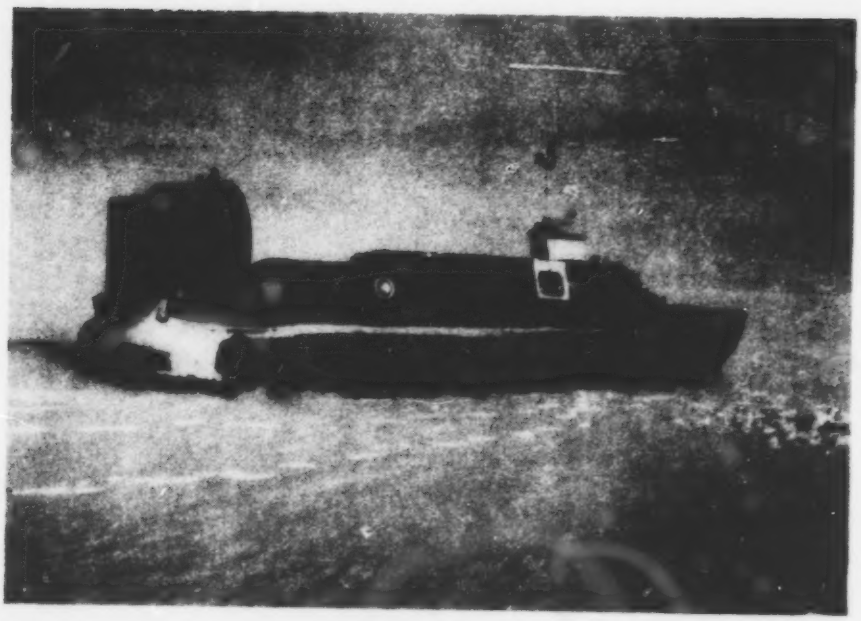
HOVERCRAFT OPERATIONS IN ANTARCTICA
Some Hovercrafts Operated in Antarctica



MV-PP05A Polar Terrain Test Craft, Japan
Dim.: 8.1m by 4.8m, load: 0.6t, Max W.: 2.8t

Air Vehicles "Tiger 4" , United Kingdom
Dim.: 5.1m by 2.4m, Load: 325kg, Max. W.: 550 kg

Tiger "4" encounter with locals.



Hover Systems Inc. Husky 1500 TD
Dim.: 10.2m by 3.8m, Load: 1.5t, Max. W.: 3.8t

HOVERCRAFT TRIALS ON SONG-HUA RIVER
(ESSAI D'UN AÉROGLISSEUR SUR LA RIVIÈRE SONG-HUA)

Zhao Jian and Gu Xiong, Marine Design and Research Institute of China

ABSTRACT

At the higher latitudes of northern China, rivers are frozen from October to May. Crossing the rivers by boat, or on ice by foot during the period of freezing and thawing is dangerous. Communications are suspended at this time. An amphibious hovercraft, MARIC model 7210, satisfied user's demands on the Song-Hua river. However, ice cresting on other rivers exceeded one metre and could not be overflown with the 7210 hovercraft. A number of observations are made concerning skirt flexibility at low temperature, freezing spray and general low temperature behaviour of this hovercraft.

RÉSUMÉ

Aux latitudes élevées du nord de la Chine les rivières gèlent d'octobre à mai. La traversée par bateau ou sur la glace durant les périodes de gel ou de dégel est dangereuse et les communications sont alors suspendues. Un aéroglisseur amphibie, le modèle 7210 de MARIC, a satisfait les demandes des usagers sur la rivière Song-Hua. Cependant, sur d'autres rivières les crêtes de glaces dépassaient un mètre, ce qui excède les possibilités de l'aéroglisseur 7210. Des observations ont été faites sur la flexibilité des jupes à basse température, le gel des embruns, ainsi que la réaction générale de cet aéroglisseur à basse température.

INTRODUCTION

Hovercraft trials were carried out on the Song-Hua river in the northeast part of China in 1986, at the beginning of the freezing season. The specifications of the hovercraft used, MARIC model 7210, satisfied user's demand. However, obstacle clearance capability of the craft was not quite satisfied for the Heilongziang and Wusuli rivers, where ice obstacles always exceeded one metre.

The rivers in the higher latitudes of northeast China remain frozen from October to May each year. Horses, persons and vehicles may cross when the rivers are fully frozen. During May and October, the thawing and freezing periods, the temperature differences between day and night are very large. This results in the ice surface fracturing during the day, with ice pans floating away. The surface is thus very unstable making it dangerous for crossing. At night, the frigid wind causes the floating ice to accumulate into ice rafts with individual floes overriding each other resulting into sharp crests pointing downwind (figure 1).

Those periods place great difficulties on the local people, with the lack of communications giving rise to a number of social problems.

Figure 1. View of Ice Surface on the River

USER'S REQUIREMENTS

The users hope the hovercraft may be useful for the traffic mission at this period of time. The main requirements specified by the users are:

1. The hovercraft is of a size that can be moved by trucks or wagons.

2. The hovercraft can be started conveniently in the morning after a night in the open at minus 20 degree Celsius.

3. The hovercraft must be supplied with a heater able to maintain a temperature of ten degree Celsius in the cabin. The cabin humidity and/or the window insulation must be controlled so that the operator view remains undisturbed by misting.

4. The hovercraft skirts will rwmain supple at a temperature of minus twenty degree Celsius and will not accumulate ice from water spray.

5. The hovercraft is expected to clear ice ridges up to 0.5 metre in height; it is to detour around areas where this height is exceeded.

HOVERCRAFT MODIFICATIONS

In order to meet the users' requirements, the following modifications were proposed on the MARIC 7210, the hovercraft used for the evaluation:

1. Double windows were installed, with sealed inner space filled with a dry inert gas.

2. An air-cooled diesel engine with flame pre-heating was adopted so that the engine could be ignited and started at minus twenty degree Celsius.

3. The accumulators were installed in an insulated box so that they could provide the necessary engine starting current when the hovercraft has been standing in the open after twelve hours at minus twenty degree Celsius.

4. Skirt fabric and coating materials, which can be operated at low temperatures of at least minus twenty degree Celsius should be developped.

MARIC 7210 HOVERCRAFT

The leading particulars of the test hovercraft MARIC 7210, shown in figures 2 and 3, are as follows:

Length overall (on cushion)	11.0m
Beam overall (on cushion)	4.5m
All up weight	5.0t
Crew	2 persons
Passengers	9 persons
Maximum fuel capacity	0.336t
Maximum calm water speed	43.8km/h
Endurance	6 hours
Skirt depth	0.5m
Skirt type	Bag-fingers

Propulsion System:

A Deutz air cooled diesel type BF6L913 rated up to 198 hp at 2500 rpm is mounted behind the cabin to drive a five bladed fixed pitch GRP air ducted propeller with a diameter of 1.80m

Lift Engine:

A Deutz air cooled diesel type BF6L913 rated up to 198 hp at 2500 rpm is mounted forward to drive an aluminium centrifugal fan with a diameter of 1.20m

Figure 2 MARIC 7210 Hovercraft

TRIALS OBJECTIVES

Trials have been carried out in order to test the capability of the MARIC 7210 with regard to the following characteristics:

1. Ice obstacles clearance from various directions.

2. Crossing of open leads between ice pans on the river.

3. Crossing of various type of ditches or trenches.

4. Handling at wind speeds up to Beaufort force 6.

5. Operational reliability of the skirts, propeller, fan, etc., under various operating conditions, from in situ inspections.

TRIALS RESULTS

1. Some of the measures taken into consideration for operating at low temperature were effective.

2. As the temperatures were always higher than minus twenty degree Celsius, the original skirt fared very well during the trials. Water spray did not freeze on the skirt and its flexibility did not change in any obvious manner.

3. The drag of the craft was small on flat ice surface but increased drastically in the areas with floating ice, just as it did on the rough ice surfaces.

4. Since no reverse thrust device had been installed on the craft, it had to be operated at sub-hump speed when crossing gaps between ice floes. In this way the craft was kept from damaging its skirt and structure by collision with ice obstacles.

5. The craft could clear rafted ice and floating ice with height not exceeding 0.5m.

6. Since the craft was operated intentionally at sub hump speed over the river ice, only a little water spray splashed on the craft. A thin ice coating of about 2mm was collected on the deck, railings, lift fan, hub of propeller and propeller bearing supports. At the same time an identical craft was operated at sub hump speed on an unfrozen lake at a temperature of minus six degree Celsius. A large water spray was generated and, consequently, very thick ice was collected on these same parts. Therefore, the key point for reducing icing is the suppression of water spray.

7. In the case of an hovercraft operating over floating ice, it has to possess good manoeuvrability with short turning diameter in order to avoid collision with ice obstacles higher than its skirt clearance.

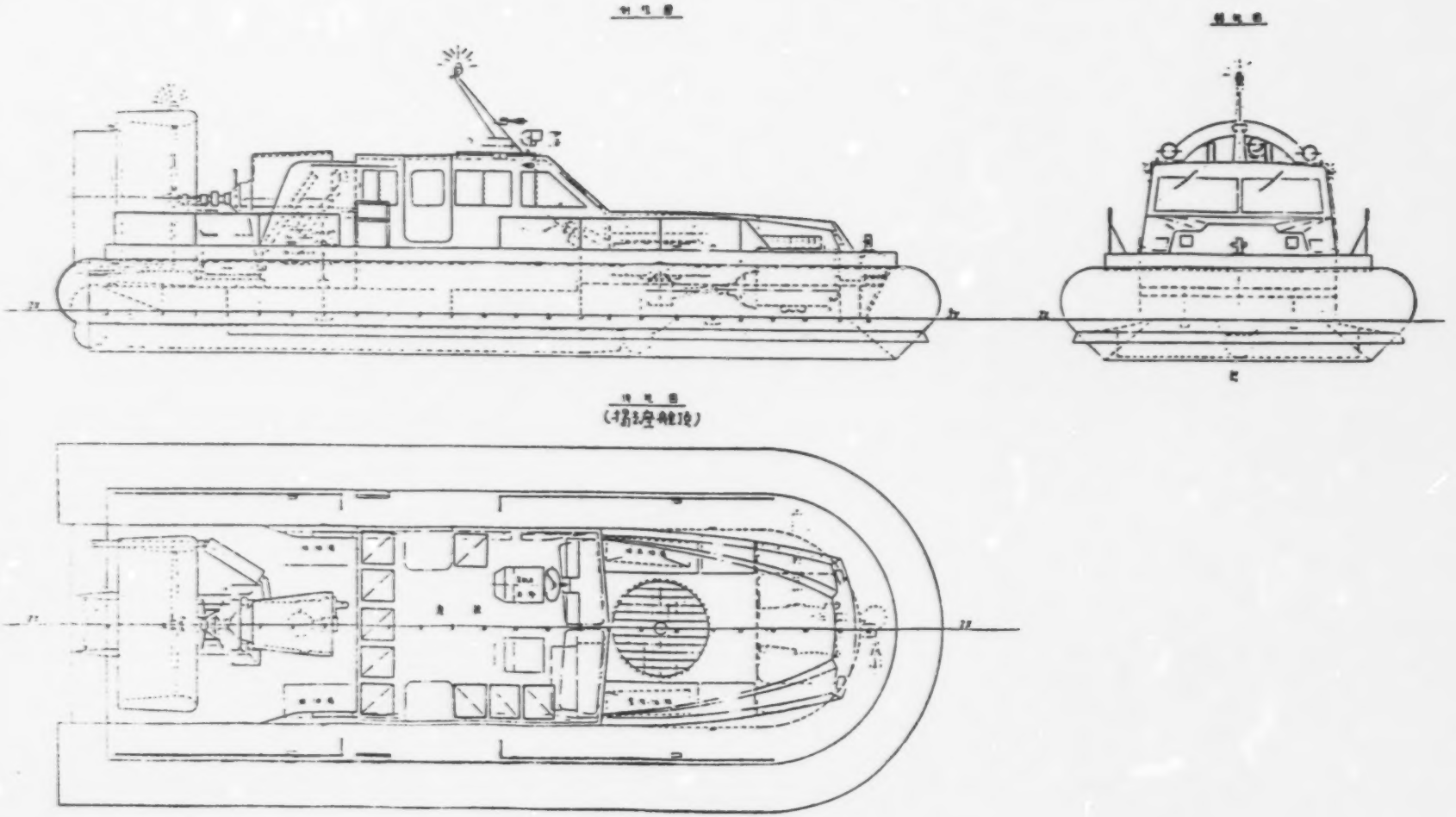


Figure 3 MARIC 7210 Sectional Diagrams

VEHICLES

VÉHICULES

TECHNICAL EVALUATION OF THE MARIC 65-TONNE AMPHIBIOUS HOVERCRAFT MODEL 722

(ÉVALUATION TECHNIQUE DE L'AÉROGLISSEUR DE 65 TONNES MARIC 722)

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ABSTRACT

The MARIC 65-tonne, piston-powered development hovercraft was evaluated over a number of years before its retirement. The craft, which had a 15-tonne payload capacity, is described along with its design rationale. Some trial results are given, covering cushion behaviour, cabin airborne noise and seakeeping characteristics.

RÉSUMÉ

L'aéroglisseur MARIC de 65 tonnes est un véhicule de développement équipé de moteurs à piston qui fut évalué durant quelques années avant d'être réformé. Il avait une charge marchande de 15 tonnes. Une description de cet aéroglisseur est faite, ainsi que les considérations ayant dirigé sa conception. Quelques résultats d'essais sont donnés sur le comportement du coussin, le bruit intérieur et la tenue en mer.

INTRODUCTION

The aim of the MARIC 65 tonnes amphibious development hovercraft model 722 was to evaluate technical performance, feasibility, practicality and applications of such medium size amphibious hovercraft in China.

The development and evaluation schedule of the craft was as follows:

Initial R&D on the craft	1974
Technical design	1975-76
Construction design	1976-77
Construction of the craft	1977-78
Watertight test of the buoyancy raft	1979
Bollard test on land	1979
Launching	1979
First long range sea trials	1980
Second long range sea trials	1980
Delivery to the user	1981
Tests in various operational environment	1981-87
Retirement	1987

MARIC MODEL 722 AMPHIBIOUS HOVERCRAFT

Leading particulars of the craft and its design performance are given below. The hovercraft itself is illustrated in figures 1, 2 and 3.

LEADING PARTICULARS

Length overall	27.4 m
Beam overall	13.9 m
Height overall	9.6 m
Length of buoyancy raft	20.0 m
Beam of buoyancy raft	7.5 m
Height of cargo cabin	2.6 m
Area of cargo cabin	80.0 m^2
Height of navigation cabin	1.9 m
Cushion length (Lc)	24.6 m
Cushion width (Bc)	11.4 m
Lc/Bc	2.16
Cushion area (Sc)	270.0 m^2
Cushion pressure (Pc)	2.4 kPa
Pc/Lc	97.5 Pa/m
Height of skirts, stern to bow	1.5-1.8 m
All up weight	65.0 t

MAIN DESIGN PERFORMANCE

Payload (cargo or two cars)	15 t
Speed, maximum calm water	54 knots
maximum sea state 3	37 knots
Maximum range at 40 knot cruising speed	200 naut. miles

Seakeeping capability:
Vehicle to operate safely on cushion in Sea State 4

Amphibious capability:
Vehicle to be operated overland and overwater

Ground obstacles clearance	1.1 m
Ditch crossing capability, width	2.5 m

Floodability:

Total buoyancy of craft/ craft weight	1.85

Buoyancy raft is divided in 19 compartments allowing floatation with two compartments flooded

DESIGN CONSIDERATIONS

In the early 70's, CSSC (China State Shipbuilding Corp.) and MARIC as well as some potential users, planned to evaluate the feasibility and the practicability of medium sized amphibious hovercrafts. These characteristics are difficult to predict from model tests or from small manned test crafts. Therefore the 65 tonnes MARIC hovercraft was designed and built in order to evaluate and predict manoeuvrability, amphibious and seakeeping capabilities, speed performance, reliability of power transmission system and skirts, etc, of a medium sized ACV in various operational environments.

This craft had to be built from material available in China. This, and the objectives to be met by the craft, led to the following design considerations and constraints.

1. Structural Material

The main hull structure use riveted duralumin (non sea water resistant) as the main material because a reliable, sea water resistant aluminium alloy was not available in China at that time.

2. Engines

There were also no China made reliable marine gas turbines available at the time, so that, in order to complete the craft within schedule, use was made of piston engines built in China. Model "651" and "690" aviation engines were used respectively as propulsion and lift engines. The main characteristics of these engines are as follows:

Engine models	"651"	"690"
Rated power (hp)	1530	1430
Fuel brand	Aviation gasoline No. 95	
Weight of each engine (kg)	935	1100
Specific weight (kg/hp)	0.612	0.769
Overhaul life (hr)	300	300
Rated revolution (rpm)	2400	2400
Maximum revolution (rpm)	2600	2600

3. Air Cushion Design

Considering the probability of craft weight increase during construction and the lack of a prototype, a low cushion pressure to length ratio (Pc/Lc=10) and a high cushion length to beam ratio (Lc/Bc=2.4) were chosen in order to reduce peak resistance. A longitudinally tapered bag and finger skirt with a slope of 1.2 (height of bow skirt over height of stern skirt) was mounted in order to improve seakeeping qualities. "D" type bag were also added to the bow skirt to effectively prevent tuck under (figures 2 and 4).

4. Lift and Auxiliary Propulsion Systems

Two aviation piston type engines model 651, each rated at 1530 hp, were installed to drive, via transmission gearbox and flexible coupling, six centrifugal fans and two propellers mounted on swiveling pylons for auxiliary propulsion. Each fan, of 1.49 m diameter, consumed 333 hp at the maximum speed of 1275 rpm.

Auxiliary Propellers: These propellers, 2.6 m in diameter, could be regulated in pitch from -13 to 19 degrees in order to balance power output between fans and propellers, and also to obtain reverse thrust from these propellers. The maximum power output for each auxiliary propellers was about 400 hp.

Fans: Six industrial fans, model 4-73, were mounted on the craft and the skirt bags used as main duct for distribution of the pressurised air (figures 5, and 8). This system was highly efficient.

Propeller Pylons: The swiveling pylon could be turned 48 degrees on either side through the action of hydraulic actuators controlled by an electro-electric system (figures 6 and 7). This improves manoeuvrability and course keeping ability in quartering wind.

Obviously, the design and manufacturing of the power transmission system, particularly the swiveling pylon, were very difficult due to the long transmission shaft. There were strong excitation sources with a wide range of frequencies to interact with the light and flexible hull structure, the light transmission shafts, bearings, gearboxes and mountings. Engines vibrations and torque oscillations, wave slamming, etc, compounded the problem.

5. Propulsion System

Two aviation piston type engines model 690, each rated at 1430 hp, were mounted on lattice towers aft, driving 3.8 m propellers.

6. Craft Control System

In order to test the effectiveness of different control devices to obtain good manoeuvrability of the craft, a number of control devices were mounted on the craft. These were:

* Two vertical air rudders with stability fins;
* An horizontal air rudder and fin (elevator);
* Differential thrust for the two main air propellers;
* Differential pitch angle for the two auxiliary air propellers;
* Swiveling pylons;
* Air duct valves for regulating the cushion pressure in forward and rear cushions so as to change the trim angle in various operational environment;
* Skirt lift system permitting transverse motion of the craft.

GROUND TESTS AND SEA TRIALS

Tests were carried out covering stability and other characteristics of the air cushion, seakeeping and general behaviour of the craft in various operational situations.

1. Static Hovering Tests

The craft was hovered freely over the ground and the bag/cushion pressure was measured at a number of locations (figure 9).

The tests showed that the cushion pressure was distributed uniformly, with a mean cushion pressure of 2.04 kPa (Pc) and a mean bag pressure of 2.32 kPa (Pt).

Pt/Pc = 1.135
Air flow rate = 250 m^3/s
Skirt clearance = 0.071 m (space between skirt tip and ground)

2. Static Stability Tests

The static longitudinal and transverse stability on the ground were measured as follows:

Mp/ψ = 314.2 m.kN/deg. $\quad \frac{Mp/\psi}{W.Lc}$ = 2.1% per degree of pitch

Mr/θ = 26.7 m.kN/deg. $\quad \frac{Mr/\theta}{W.Bc}$ = 0.4% per degree of roll

Where	M	Restoring moment (m.kN)
	W	Craft weight (kN)
	ψ	Pitch angle (deg)
	θ	Roll angle (deg)

3. Calm Water Speed Tests

Tests to measure the maximum calm water speed and corresponding cushion pressure were carried out in Qing dao in 1980. Figure 10 shows the thrust and drag of the craft versus the speed. It was found that the cushion pressure of the craft at top speed was also distributed uniformly. The mean cushion pressure was reduced a little because of the aerodynamic lift of the craft at speed.

Maximum velocity measured,	V = 28.2 m/s (54.8 knots)
Craft weight during test,	W = 59.1 t
Cushion pressure,	Pc = 1.88 kPa
Bag pressure,	Pt = 2.39 kPa

4. Manoeuvrability Tests

Manoeuvrability tests were carried out in Qing dao. Manoeuvrability of the craft was satisfactory, not only at high speed on cushion, but also at low speed, due to its effective control devices. With control through the air rudders, the turning diameter of the craft was about 6.4 L at a speed of 30 km/h and 19.5 L at 50 km/h.

5. Airborne Noise

Inside airborne noise was measured in various part of the craft; the measurements are given in the table below. The external airborne noise, measured 50 m from the rear of the craft, was about 95-100 dBA. The noise level, both internally and externally, was high due to the experimental nature of the craft.

Location	Airborne Noise (dBA)
Forward passenger cabin	82-84
Navigation post	101
Radio cabin	93
Cargo area	98-106
Machinery bay (starboard)	116

6. Long Range Continuous Operations

The craft has been operated continuously on two occasions in 1980. The first time was from Tien-Jin to Qin huang dao (figure 11) and return (240 naut. miles), the second time, from Tien-Jin to Qing dao (550 naut. miles). These trips showed that the craft endurance was satisfactory.

7. Amphibious and Obstacle Clearing Tests

These tests were carried out in 1979 and 1980 (figures 12, 13 and 14). They showed that the craft could clear a clay obstace of 1 to 1.1 m, cross a ditch 2.5 m wide and traverse a maximum gradient of 3% in a short distance.

8. Seakeeping Tests

Seakeeping tests were carried out in July of 1981 in Qing dao. The test results are shown in the table below.

Parameters	Mean Values for four Routes			
	1st (head sea)	2nd (following sea)	3rd (head sea)	4th (following sea)
Pitch angle (deg)	5.33	2.59	5.46	4.14
Roll angle (deg)	5.13	2.03	4.30	2.02
Bow acceleration (g)	0.23	0.12	0.23	0.11
Pressure fluctuation				
Front cushion (kPa)	0.91	0.56	1.36	0.50
Rear cushion (kPa)	1.10	0.59	1.27	0.79
	Maximum Values for Routes			
Pitch angle	12.34	6.17	12.36	7.45
Roll angle	15.64	4.94	14.94	3.92
Bow acceleration	0.61	0.25	0.63	0.25
Pressure fluctuation				
Front cushion	2.59	1.18	4.04	1.46
Rear cushion	2.63	1.13	2.57	1.85

Wave Characteristics			
Fraction of waves	100%	33%	3%
Mean wave height (m)	1.09	1.65	2.18

Figure 15 shows the time history of the pressure fluctuations in the bags and in the front and rear cushions.

SUMMARY

I Trials of the medium size air cushion vehicle model 722 has been carried out over a long period of time, during which a lot of data and experience has been accumulated. This has been very important for later designs and operations.

II The test results in various environments show that hovering performance, speed, stability, manoeuvrability, strength of hull structure, power transmission system (including fans and other rotating machinery), skirts, etc, were satisfactory.

III The trials showed that the practicability, feasibility and maintainability of the various components of the craft were not satisfactory, and that there was still room for improvments.

IV The craft could have benefitted from the use of responsive skirts with larger deformation and better ride control. The effectiveness of such skirts has been demonstrated both in static test rig and in towing tank experiments.

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3. Zheng Chong Qing, Chen Li Ying: "Test and Analysis of the Cushion/Bag Pressure and its Fluctuation on the 65 tonn Amphibious Hovercraft" MARIC Report 1982

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5. Yun Liang: "Development of Hovercraft at Home and Abroad During the Last Decade" The Second Conference on High Speed Craft in China, 1984

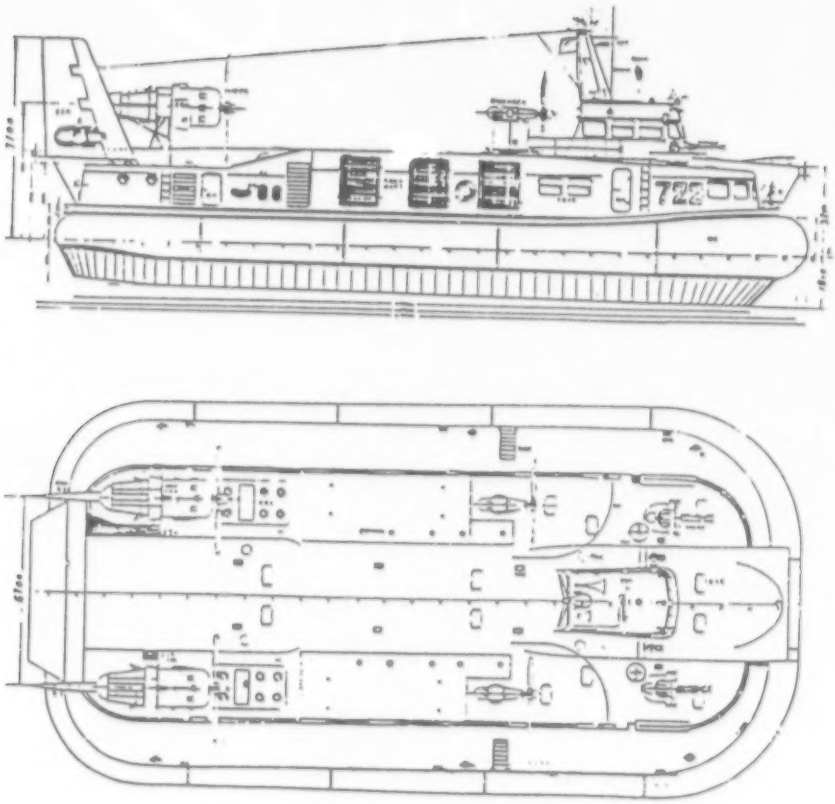


Figure 1. MARIC Model 722: Side and Plan Views

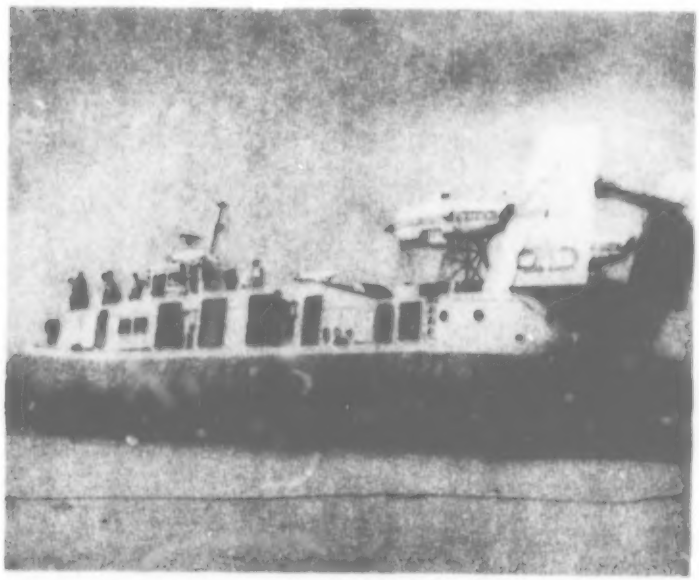


Figure 2. MARIC Model 722: Craft in Static Hover

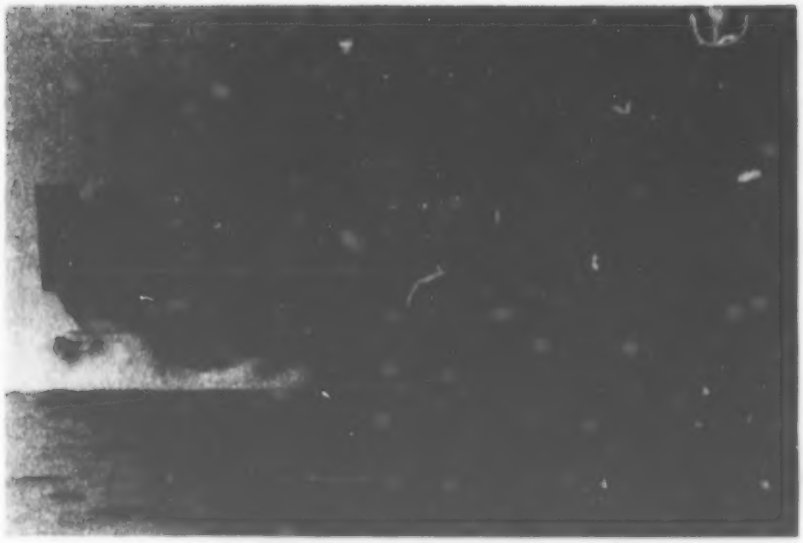


Figure 3. MARIC Model 722: Craft at Speed

Figure 4. MARIC Model 722: Side Skirts

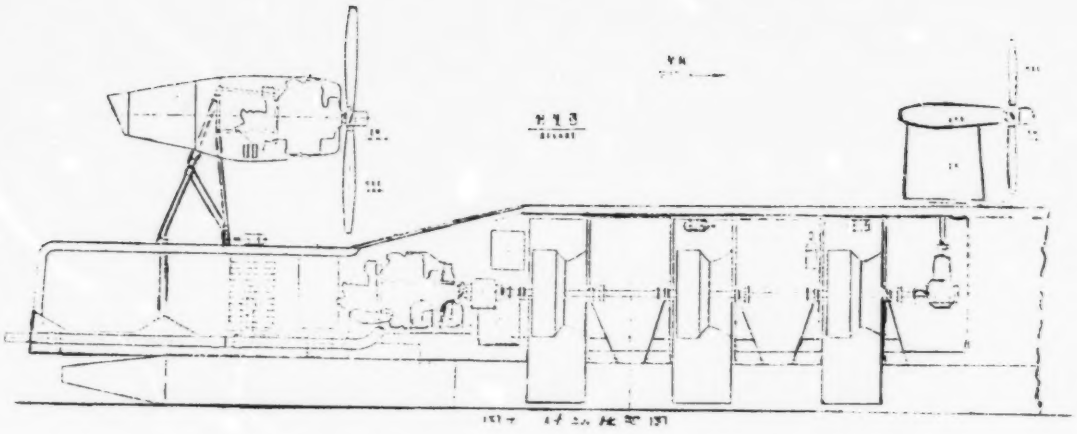


Figure 5. Arrangment of Power Plant and of Lift/Propulsion System

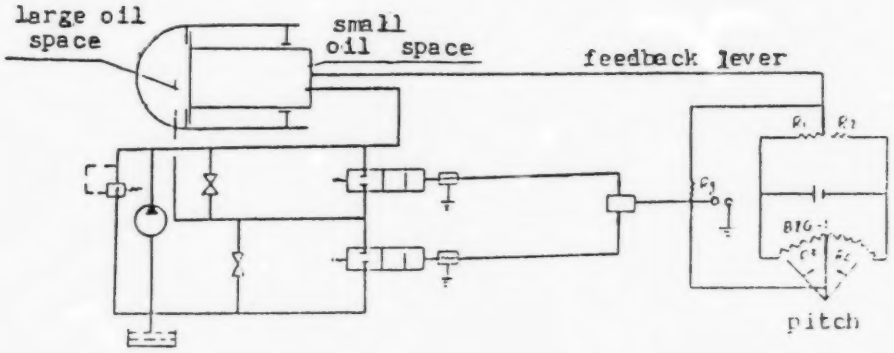


Figure 6. Diagram of Pitch Control System for the Auxiliary Propeller

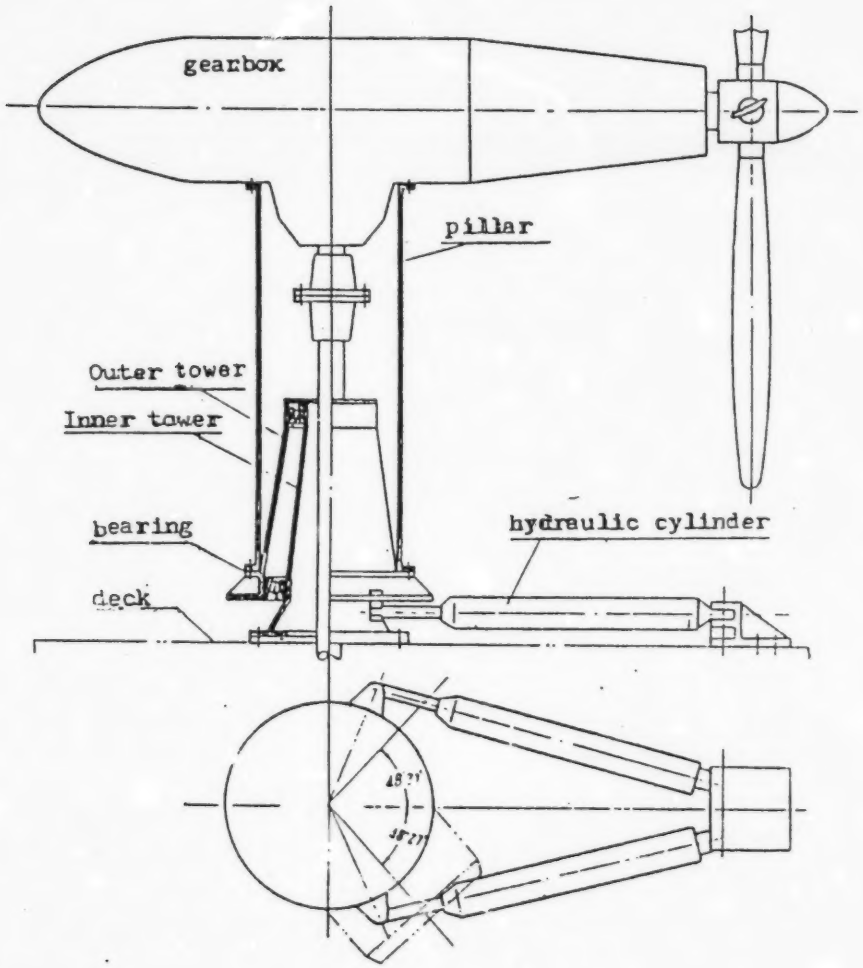
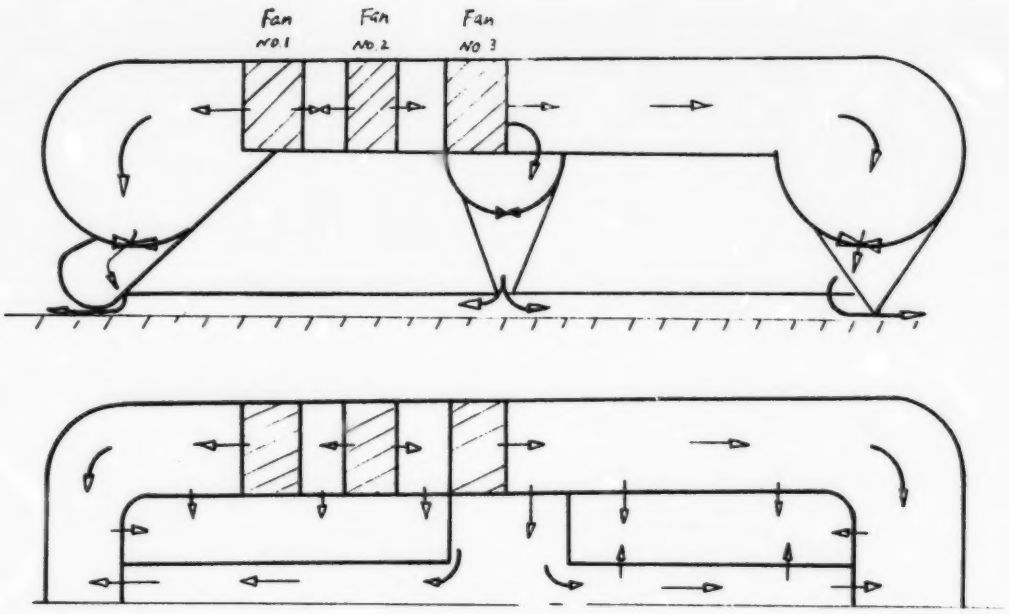
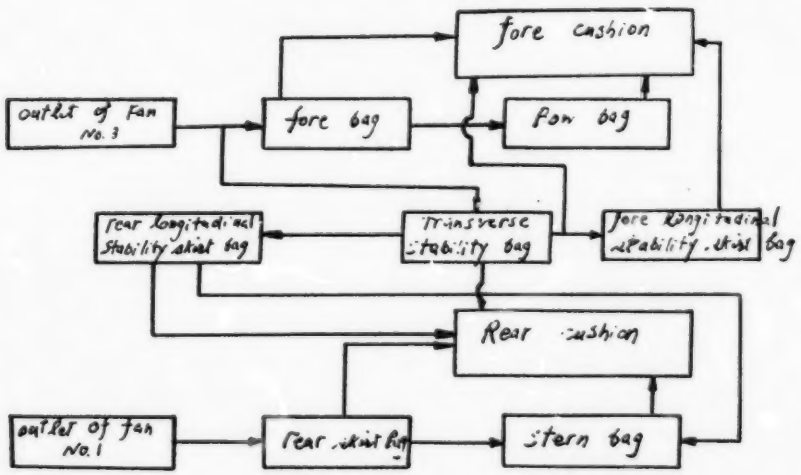


Figure 7. Sketch of the Swiveling Pylon



A) Distribution Channels on Port Side



B) Air Flow Circuits

Figure 8. Cushion Air Flow Distribution

Location of Measurement Points	1. Front Cushion (Port)	2. Front Cushion (Starboard)	3. Rear Cushion (Port)
Pressure at Static Hover (kPa)	2.05	2.11	2.11
Pressure at Top Speed (kPa)	1.99	2.06	1.81

	4. Rear Cushion (Port)	5. Rear Cushion (Starboard)	6. Bow Bag (Port)
Pres. Static Hover	1.99	1.72	2.36
Pres. Top Speed	1.81	----	2.65

	7. Stern Bag (Port)	8. Bow Bag (Starboard)	9. Stern Bag (Starboard)
Pres. Static Hover	2.40	2.35	2.36
Pres. Top Speed	2.06	2.70	2.16

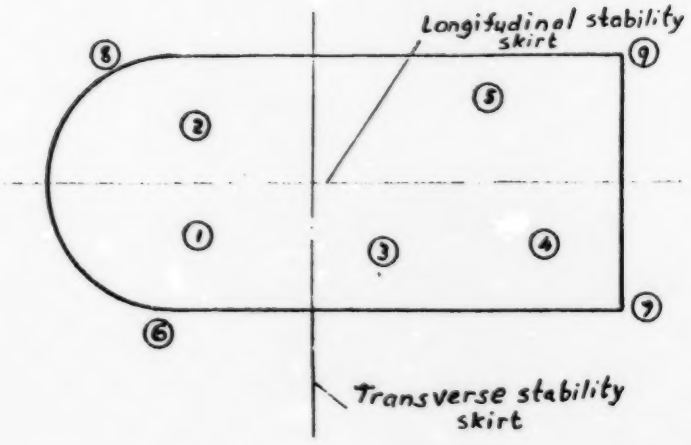


Figure 9. Bag and Cushion Pressure at Various Locations

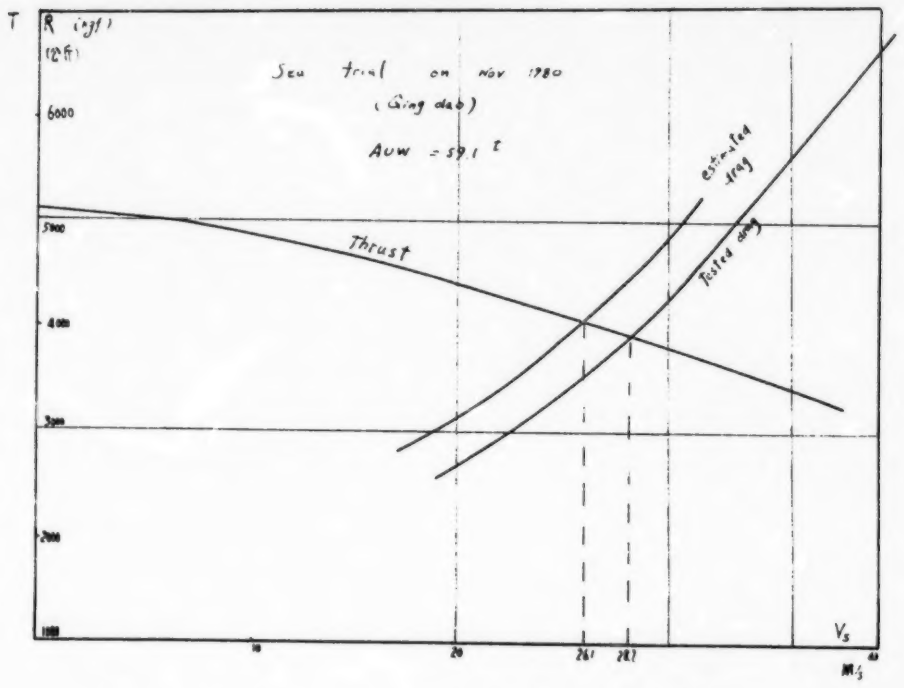


Figure 10. Thrust and Drag of MARIC Model 722

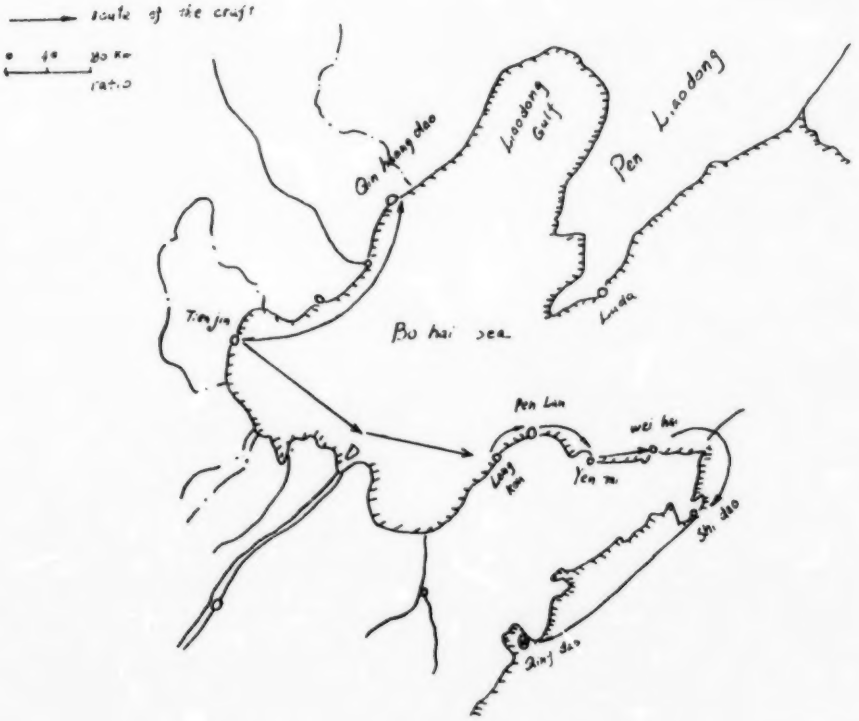


Figure 11. Trial Area and Craft Route

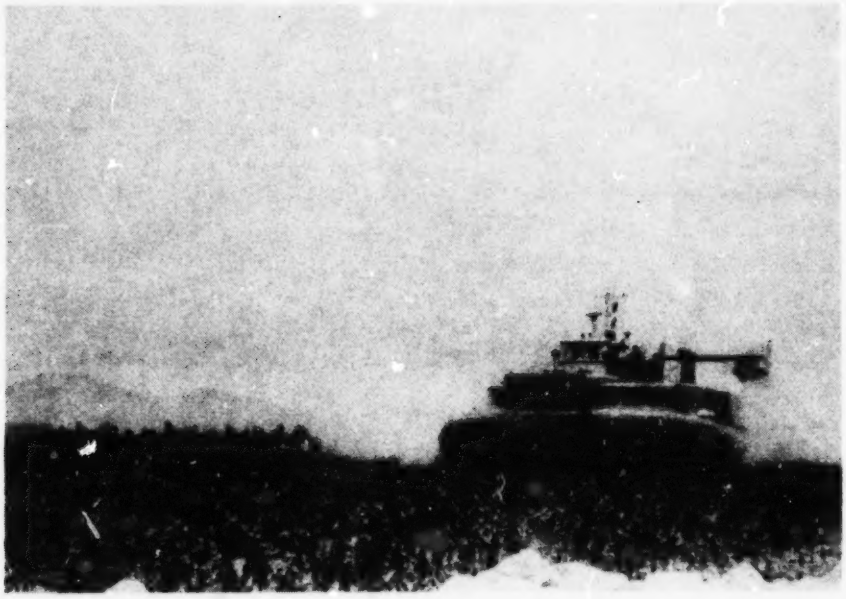


Figure 12. Operation on Maize Field

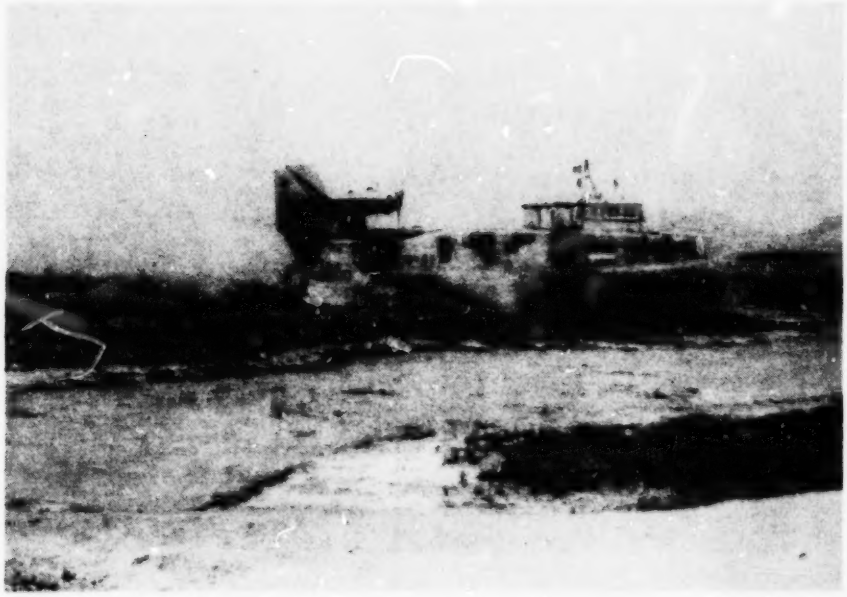


Figure 13. Crossing a Complex Ground Area

Figure 14. Crossing Clay Obstacles

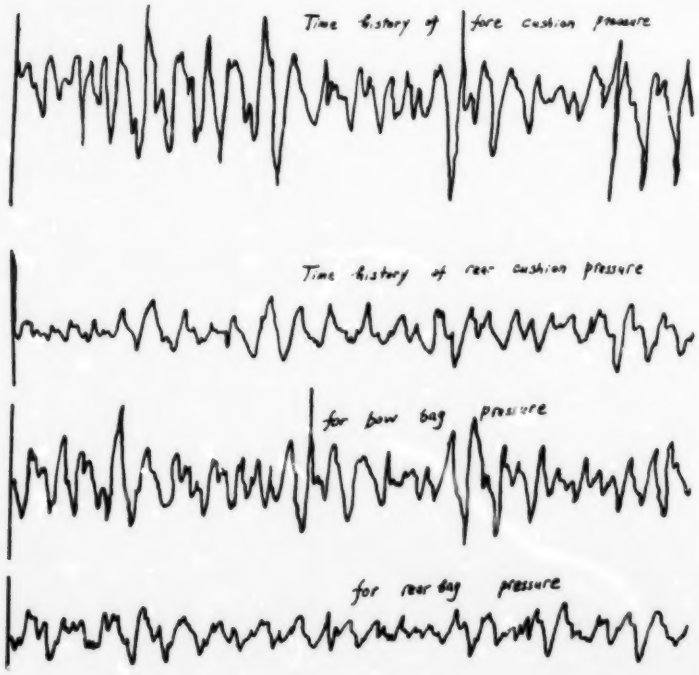


Figure 15. Time History of Cushion and Bag Pressures